ESTIMATING THE INVENTIVE ACTIVITY OF UK FIRMS: PRODUCT AND PROCESS INVENTION

Pamela A. Siler

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ABSTRACT

This thesis concerns the development and estimation of models of firm decision-making with respect to inventive activity. The thesis is unique in its separate treatment of improvements to the firm's product technology and improvements to the firm's production technology. The two types of inventive decisions are separated in both the theoretical and empirical sections of the thesis. The firm decision-making models of product and process invention are tested on the 180 largest manufacturing firms in the U.K. While a number of U.S. studies have been undertaken using this cross-sectional approach, there have been no comparable studies using U.K. data.

Empirical tests in the thesis are conducted using mid-1970's patent data as the measure of inventive activity. Difficulties surrounding the use of this and other possible measures of technological change are highlighted in the study. The measurement of a number of independent variables influencing inventive activity, such as technological opportunity, is also discussed.

Major findings of the thesis are concerned with the effect of firm size, industry concentration and technological factors on product and process invention. While the study is mainly concerned with the 180 firms taken as a whole, a breakdown of results by general industry category is provided.

I declare that this thesis has been composed by myself and that the work incorporated in it is my own.

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CHAPTER ONE

INTRODUCTION

1.1 The Economist's Interest in Technological Change

The recognition of technological change, or the addition to society's stock of technical knowledge, as a distinct topic for economic analysis has been relatively recent. Only within the past two decades has there been a steady progression of work related to technological change as an economic variable, at least partially determined by economic forces. Prior to this time technology was generally accepted by economists as a variable determined outside the economic system. Although a few earlier economists might be interpreted as taking a more endogenous view of technology, this approach was not pursued or emphasised by their followers.

Economists' interest in technological change goes back to Adam Smith who discussed the impact of new machinery on the division of labour. Smith (1950, p.14) also made some brief observations concerning the source of the new machines, which might be invented by: (1) common workers to assist them in their jobs; (2) those in the business of machine-making; and (3) philosophers, 'whose trade it is not to do anything, but to observe everything.' Other early economists, such as Ricardo (1970), also evaluated the impact of new techniques of production, but not in any depth and only in connection with other interests.[1]

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1. Ricardo, for example, discussed the effect of improved machinery on the costs of production and selling prices in foreign markets.

Marx paid considerable attention to the role played by technological change in capitalist development. In particular he (Marx, 1894) pointed to the effect of continuous improvements in machinery on the rate of profit. Yet Marx is credited by many analysing his work as having an exogenous view of technological change - determining but not determined by economic phenomena.[1] Rosenberg (1976) argues, however, that Marx has been misinterpreted and that a correct interpretation of his work would stress the mutual interactions between economic variables and technology.

In this century Schumpeter was instrumental in bringing technological change to the attention of economists. In his analysis of business cycles, he (Schumpeter, 1939) characterised new technology and particularly new products, as having an unstabilising effect on an industry, as capital was withdrawn from older businesses and made available for new purposes. These instabilities tended to right themselves however, and their effect was not cumulative. In the long-run Schumpeter (1934) saw the process of innovation, which he designated as the entrepreneurial function, as one of the elements playing a central role in economic development.

Schumpeter (1928, p.384) may be best known with respect to technological change for his view that 'trustified' /

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1. See Hansen (1921) for a discussion of Marx's technological determinism.

'trustified' rather than 'competitive capitalism' was the market structure most conducive to a rapid rate of change. In 'trustified capitalism' innovation met with less friction due to a longer term view towards investment and the power to accumulate reserves.

While emphasising the importance of technological change in economic life, Schumpeter did not explicitly address the process by which new technical knowledge was generated.[1] Therefore while it determined economic events, technological change itself, was treated as an exogenous variable.

Also in the 1930's, Hicks, in considering the labour-saving or capital-saving bias of technological change, developed an economic theory of invention.[2] Hicks argued (1932, p.124) that 'induced inventions' were the result of a change in the relative prices of the factors of production.
Changed relative prices would stimulate the search for new methods of production which would use more of the now relatively cheaper factor and less of the expensive one, which was expected to be labour. According to Hicks, 'induced /

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1. Schumpeter (1934, pp.84-85) separates the use of knowledge by the entrepreneur or innovation from the creation of knowledge or invention, describing them as entirely different economically and sociologically. Invention, he points out, does not necessarily lead to innovation or on its own produce any economic effect at all.

2. Hicks (1973, p.76) later argued that the traditional labour-saving verus capital-saving classification was inappropriate. A more appropriate classification for inventions was their 'forward-bias' (towards consumption) or their 'backward-bias' (towards investment).

'induced inventions' could be contrasted to all of the rest - or 'autonomous inventions' which were not dependent on relative price changes, and therefore not necessarily labour-saving.

Hicks' theory stimulated considerable discussion concerning the bias of technological change.[1] However, it does not seem to have stimulated economists to investigate the economically induced process of change at the level which invention takes place, with the firm or individual. This may be due to Hicks' emphasis on the benefit to the user of inventions rather than to the producer, which might be a different firm or individual. He (Hicks, 1932 p.121) refers to the profit-motive as an incentive for firms to adopt cost-reducing inventions, stressing the benefits in terms of liberated resources which increase the 'National Dividend'.

Interest in technological change was further stimulated when, in the mid-1950's, empirical findings were reported showing it to be the major determinant of economic growth in the US economy over recent decades.[2] Although considerable controversy developed concerning these results, they were reputable enough to provoke economists /

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1. Salter (1960) challenged Hicks' theory of induced invention, proposing instead that any advance which reduced total cost would be welcomed by an industry, whether it be labour-saving or capital-saving.

2. These findings are briefly discussed in section 1.2.

economists into considering technological change as an area for serious inquiry. As Abramovitz (1956, p.11) remarked, it was 'in a sense sobering, if not discouraging to students of economic growth' that the major contribution was made by a phenomenon economists knew little about.

By the early 1960's, theories were emerging which treated technological change as an endogenous variable. Schmookler (1962, p.1) declared that 'technological progress is intimately dependent on economic phenomena'. His point was that the incentive to produce an invention, like the production of any other good, was affected by the excess of expected returns over expected costs.

In the last two decades there has been significant activity amongst economists in expanding, challenging and testing endogenous theories of technological change. This thesis will follow that line in testing endogenous theories at the firm level in the United Kingdom.

The development of technological change as an economic area of study points to a dichotomy which will be emphasised in this thesis - the distinction between technological changes in products and changes in production processes. The general approach in previous studies has been to restrict the discussion to either: cost-saving inventions, as emphasised by Hicks, or product-enhancing inventions bringing greater revenue to the firm from the market place and as emphasised by Schmookler. This study's approach will be to recognise both /

both types of inventions and to explore the economic rationale behind each type.

A much neglected feature of Schmookler's work which this thesis emphasises is his insight that every industry has two technologies: a 'product technology' or the technical knowledge used in creating and improving products and a 'production technology' or the technical knowledge used in producing products (see Schmookler, 1966, p.88). Schmookler concentrated on product changes in the capital goods industry, which reduced costs in the industry purchasing and using the capital goods.

In concluding this section, it is worth remarking that although interest in the subject has increased substantially over the past two decades, technological change remains outside the generally accepted body of economic theory. Compared with the current somewhat overwhelming popular interest in the subject, the economists' interest must still be seen as weak.

1.2 Economic Effects of Technological Change

This thesis, in considering the generation of new technical knowledge by firms, concentrates on the net benefits of technological change which the firm can internalise. However, in doing so, it is useful to keep the wider social benefits and costs of technological change in mind, particularly if any assessment is to be made of the performance of firms in generating new technology from society's point of view. In this section, the positive and negative effects of new technology /

technology are outlined, first at the aggregate level and then at the firm level where technology is generated. The effects of new technology on the industries within which the firm operates are also discussed.

Aggregate effects An interest in technological change by economists is fully justified given its importance in determining economic welfare. Technological change can increase welfare quantitatively, generating increases in real income per head. New knowledge concerning the techniques of production has the effect of shifting the production boundaries outward, giving increased output for the same level of inputs. Alternatively by using fewer labour inputs to get the same level of output, leisure can be increased. This is relevant not only in industrial production but also household production, where improved domestic appliances can reduce labour time.

Changes in technology also improve human welfare in a qualitative sense with the introduction of new and improved consumer products. Usher (1964, p.280), treating the introduction of new products as the 'archtype of economic progress,' shows that technological change leads to the creation of entirely new production possibilities, enabling communities to move to higher indifference curves.[1] More recently Rosenberg (1982, p.4) emphasises the 'bewildering array of entirely new goods' which point to product innovation as perhaps 'the most important long-term contribution of technical progress to human welfare.'

There /

1. Usher proves graphically that any commercially profitable product invention confers a net benefit on the community as a whole.

There has been considerable effort amongst economists to measure the quantitative benefits of technological change in the form of increased productivity at the aggregate, industry and firm levels. The much more difficult measurement of the qualitative benefits has not understandably received the same attention, although recently some progress has been made in this direction.[2]

It should be stressed that not all of the effects of technological change are beneficial. Social costs of new technology may include pollution, a faster rate of exhaustion of natural resources, the proliferation of nuclear weapons which may be increasingly difficult to control and prolonged structural unemployment. For example, Giarini and Louberge (1978) point out that technological change affects pollution both quantitatively and qualitatively. Such changes allow a larger population to consume a greater amount of goods thus compounding the waste problem. Also new and perhaps toxic materials may be resistant to the natural recycling process. Paradoxically technology can also aid in solving many of the problems it creates, as new methods for dealing with industrial and domestic waste are introduced and as new production techniques are introduced /

2. Lancaster's (1966) theory of consumer demand using a 'goods-characteristics' approach has aided the analysis of product quality changes. The theory has been applied empirically through the use of hedonic price indices. For an example, see Cowling and Cubbin (1971).

introduced, which reduce the amount of resources devoted to a given amount of output.

The threat of technological unemployment is particularly troublesome at the present time as capital machinery embodied with the new microelectronic technology replaces labour. An important question is whether the increased rate of growth due to the use of new technology in production processes and its application in new products will create more jobs than are destroyed.[1] Even if an increase in employment proves to be the case, the benefits of the new technology will not be shared evenly throughout society. A period of prolonged unemployment for many in the traditional heavy industries seems inevitable, as the distribution of skill requirements changes. These issues however, while of great importance, are not the concern of this thesis and will not be further discussed.

Effect on Aggregate Growth Rates Economists' interest in the subject of technological change, as mentioned previously, was stimulated by the findings of Solow (1957) and others in the 1950's that this phenomenon, rather than an increase in factor inputs played /

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1. For a discussion of the effect of new technology on employment see Bourdon (1979) and Freeman, Clark and Soete (1982).

played the dominant role in determining 20th century growth.[1] In such macro-level growth studies an aggregate production function approach was used. Productivity improvements due to technological change were measured as a residual after the increase in labour and capital inputs were accounted for. A measure of technological change therefore became its quantitative effects on the growth of productivity.

Not all economists have attributed such an overwhelming role to technological change in the growth process. Critics of the Solow findings argued that not all the residual productivity increases should be identified as attributable to new technology. For example, empirical studies in which adjustments were made for quality changes in factor inputs assigned a much smaller role to innovation in determining growth.[2] Also Leibenstein (1966) has argued that significant increases in aggregate productivity stem from 'X-efficiency' or the use of capital, labour, management and knowledge to greater capacity. This narrows the difference between actual costs and minimal attainable costs for a given level of output.

Despite some question as to the extent to which new technology determines productivity increases, a relationship between the growth in knowledge and the growth in output /

1. For a review of aggregate growth studies see Kennedy and Thirwall (1972). Nelson (1981) summarises more recent studies of aggregate productivity growth.

2. Criticisms of the aggregate production function approach to productivity growth are found in both sources in footnote 1.

output has been established and accepted by economists. More recently attention has turned to explaining the slowdown in productivity growth during the 1970's.[1] Griliches (1980a) finds, in an empirical study using U.S. data, that it is not a slowdown in investment in new technology, but more likely the collapse in the productivity of the new technology which is the contributing factor to slow growth over the last decade.[2] He more positively notes that surveys of new technological possibilities seem to contradict any notion that productive innovations have been exhausted. For Europe and Japan, Giersch and Wolter (1983) and Linbeck (1983) suggest that the end of the technological catch-up period (with the United States) played a part in the slowdown in productivity growth.

It should be noted here that it is the use of new technical knowledge, rather than its production, which is important to economic growth. In fact, studies show little relationship between a country's level of R & D expenditure /

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1. The Royal Economic Society held a 1982 conference on the recent slowdown in productivity growth. A number of the papers presented are found in The Economic Journal (March 1983). The Giersch and Wolter and the Linbeck studies cited in the text are included.

2. Griliches, estimating investment in new technology as R & D expenditure, cites a number of factors which might explain the fall in productivity of R & D including: (1) the large fraction of R & D investment devoted to environmental and regulatory constraints on firms; (2) the slowdown in capital growth in which new technology is embodied and; (3) the chancy and fickle process of invention.

expenditure, which may be looked upon as an input into the 'knowledge production function', and its aggregate growth rate.[1] Thus while a country may not devote a large amount of resources to knowledge production, it may be an extensive purchaser of technical knowledge through licensing arrangements. Another explanation for the lack of a relationship between R & D and aggregate economic growth, is that much R & D effort goes into final product improvements which are not likely to be included in growth indices.

Tests of the relationship between R & D activity and the rate of growth of output have been somewhat more successful at the industry and firm levels.[2] However, a number of economists, including Griliches (1973) have pointed out the difficulties posed by product improvement at the industry level. If much of the R & D expenditure is devoted to improved capital goods, productivity improvements will show up in industries using these goods and not necessarily in the originating industry. Domar (1969, p.45) referred to a similar phenomenon when he noted 'the striking micro-character of the process of invention and technical change'. He suggested that it might be possible to distinguish between active industries largely responsible for their own technological improvements from passive ones which enjoy the fruits of other industries efforts.

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1. For a review of the evidence see Kennedy and Thirwall (1972)
2. See for example Griliches (1973) and Mansfield (1980).

Effects at the firm and industry levels The recent advent of microelectronics, rendering traditional production processes and products obsolete, has accentuated the role of technological change in a firm's economic performance. The growth, profitability or mere survival of firms in some industries depends on the rate at which innovations are introduced or at which innovations made by other firms are imitated.

Technological change bestows economic benefits on firms by allowing them to introduce new production techniques which lower costs. Lower production costs lead to greater profits at a given level of output or a larger sales volume if the firm's product is price elastic. It is important to note that firms do not necessarily have to produce the knowledge leading to new production techniques themselves. In fact Salter (1960), Eichner (1976) and others argue that most production process changes occur through the purchase of improved capital goods, embodying new technology.

New technical knowledge also allows a firm to introduce new and improved products which enable it to capture larger market shares and earn more profits. If the firm is in an industry where competition is on the basis of product technology, rather than price, it may be forced to continually make product changes, merely to survive.

A number of economists and industrialists argue that the essence of a firm's competitive strength in the modern world is the technical uniqueness of its product and not its low price. In particular, technological product rivalry /

rivalry is emphasised as a major factor in a firm's ability to capture export markets. Pavitt (1980) concludes that U.K. firms are producing unsophisticated machinery and consumer durable goods embodying little technological advance. This lack of product sophistication has been named as an important factor in the loss by the U.K. of industrial markets to the rest of the world, accentuating the problem of 'de-industrialisation'. More positively, an increasing attentiveness to product innovation has been advocated as a means of halting the decline of U.K. industries.

It is also argued that British firms should enter as rapidly as possible the emerging 'high-tech' industries of microelectronics, information technology and bio-technology. These industries are seen as the providers of the markets, profits and jobs of the future. Many would go a step further and argue that the rapid diffusion of microelectronic applications throughout British industry is necessary if substantial portions of industry are merely to survive.

Although the above advice seems to reflect the concensus, it has not been accepted without question. For example, Jewkes (1972) argued in favour of producing the 'mundane' rather than the 'airy-fairy stuff.' He supported his case with evidence (although somewhat dated now) showing that the products growing fastest in world trade are not those with a high-technology content. His frontrunners were furs, furclothing, watches and clocks, footwear and musical /

musical instruments.

However, in relation to the traditional industries, Aujac (1973) observes that as technologies become more science-based, there will be growing technical interdependence of economic activity. Inventions in one industry will affect products and techniques in other sectors which were once considered unrelated. This certainly has been the case in the watch industry, which has been transformed in the last decade by advances in electronics and which was one of Jewkes' traditional industries earlier in the decade.

Lastly, changes in technology have a significant effect on the size of firms and the levels of concentration within industries. New techniques of production may have the effect of either increasing or reducing the minimum optimum scale of plant necessary to achieve lowest average cost of production.[1] Whether concentration is increased after a technological change which allows for an increase in the scale of production depends on the growth of the market in the industry concerned. If demand is stagnant or increasing at a relatively slow rate, the dominance of a few firms in the industry is likely to increase. The introduction of product innovations by firms can also affect concentration by changing market shares in favour of a few leaders. Technological product superiority can act as an effective industry entry barrier.

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1. Although technological change through the nineteenth and most of the twentieth century has generally had the effect of increasing the minimum optimum scale (MOS) of plants, the pattern may be changing somewhat. Bollard (1983), Gold (1981) and Jones (1983) cite instances of new technology leading to reductions in MOS.

Given the effects of technological change described in this section, it would be hard to ignore the importance of technical knowledge as an economic resource worthy of investigation. In this thesis we are especially concerned with explaining the production of new technology by firms, considering both the benefits and costs of knowledge generation. Although firms would have no incentive to generate new knowledge if there were no gains they could internalise, it is not true that all the benefits of new knowledge will accrue to the generating firm. Other firms who are able to imitate the new knowledge in their processes and products will also be beneficiaries.

Firms face other difficulties in appropriating all of the benefits of their own knowledge generation. If a firm in the capital goods industry produces a product invention which is applied in an improved machine, it is likely to see some of the benefits going to the purchasing and using industry. The consumer could also benefit if due to the machine, there is a fall in the final product price. Mansfield's and other's findings (1977b) show private rates of return from industrial innovation (the first use of new technical knowledge) to be much lower than the social rates of return when the external beneficiaries are also considered (other firms and consumers). It is useful to keep such external benefits, as mentioned above in mind, in considering the firm's decision to divert resources to the generation of new technical knowledge.

1.3. /

1.3 Definitions and Distinctions

The phenomenon of technological change has, up to this point, been referred to in a general or popular sense.[1] However, prior to proceeding with an economic analysis in the subject area, it is important to define the concept more precisely and to distinguish it from other associated concepts. It is also useful to define and describe the separate stages of the process of technical knowledge production and use, which will be referred to throughout the thesis.

A Definition of Technological Change Technology, according to Kennedy and Thirwall (1972, p.12) may be defined as 'a body of useful knowledge pertaining to the art of production'. It consists, quoting Nordhaus (1969a, p.4) of such things as 'blueprints, labour skills, computer programs and engineering formulas', which are useful in producing goods. Technology or technical knowledge, used in this thesis interchangeably, may be distinguished from basic or general knowledge, which consists of the laws of nature and general scientific principles. Basic knowledge is knowledge for its own sake, without any application in mind. It can however, be used, together with labour and capital, to produce technical knowledge.

Technological /

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1. The term technical progress is also commonly used, sometimes in place of technological change. Economists however, generally use the phrase 'technical progress' to refer to the changes in national product over time that cannot be explained by input increases. It refers to an effect of technological change rather than to change itself. For a discussion, see Norris and Vaizey (1973, pp.24-25).

Technological change then, is a change in the body of technology no matter what the cause. The technical knowledge base may expand over time as more and more knowledge is accumulated. An expansion in knowledge might result from: the formal research effort of firms, the government or universities; the inventive effort of an individual; experience in production or 'learning-by-doing'; or even a chance discovery. With reference to the definition above, technology is also subject to contraction as some knowledge becomes obsolete or no longer useful.

Technological change has been distinguished by a number of economists from technical change or a change in production techniques. The distinction is important because known, but previously unused, techniques may be applied due to, for example, a change in factor prices. A change in technique represents a movement along the production-possibility frontier, rather than a movement of the frontier itself, which is technological change.

It should be noted that much of the overall productivity increase in an economy over time, which has been associated with technological change, may not fit into the definition used here. For example, the process of diffusion of technical knowledge throughout an industry, which may significantly increase productivity may involve no expansion of the knowledge base. Salter (1960) pointed to the long lag between the adoption of new techniques /

techniques in the 'best-practice' firms in an industry and the other firms.

Product and Process Technologies It is essential for the purposes of this thesis to differentiate, as did Schmookler (1966), between an industry or firm's product technology and its production or process technology. A product technology consists of a body of knowledge concerning the technical characteristics of the firm's products, as distinguished from design or merely visual characteristics. A process technology consists of a body of knowledge concerning the method by which a given product is produced. Schmookler viewed the two types of technologies as related but none-the-less distinct. In principle this may be valid, however in practice, as we shall see in the following chapters, the separation of the two bodies of knowledge may be more difficult.

Technological change, as previously mentioned, may result by chance discovery or as a by-product of the production process itself. However, as science-based technology becomes more important to industry, corporate inventive activity has become increasingly formalised in the research laboratory. It is useful therefore to define and describe the separate states of the formal knowledge production process and the use of this knowledge in commercial ventures.

Research and Development The firm takes a first step toward technical knowledge production when it initiates a research and development program. It diverts scarce resources /

resources to purchase capital, labour and materials to be devoted to this purpose. Research and Development expenditure (R & D) is officially defined as follows:

> creative work undertaken on a systematic basis to increase the stock of scientific and technical knowledge and to use this stock of knowledge to devise new practical applications.[1]

The government, for the purposes of compiling statistics classifies R & D expenditures into the three categories below:

> Basic research is original investigation undertaken in order to gain new scientific knowledge and understanding. It is not primarily directed towards any specific practical aim or application.
>
> Applied research is also original investigation undertaken in order to gain new scientific or technical knowledge. It is, however, directed primarily towards a specific practical aim or objective.
>
> Experimental development is the use of scientific knowledge in order to produce or substantially improve materials, devices, products, processes, systems or services.[2]

It is clear from the above definitions that basic research /

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1. see Central Statistical Office, <u>Research and Development Expenditure and Employment</u> (1976, p.2) In compiling U.K. official R & D statistics, the definition agreed upon by the Organisation for Economic Cooperation and Development (OECD) is used.

2. See reference cited in footnote 1.

research expenditure is associated with the production of basic knowledge and not technical knowledge. Although a few firms undertake basic research, R & D surveys show that it is mainly an activity of the government and of universities.[1] This is to be expected since basic research is not aimed at practical applications which can be exploited commercially by a firm. Basic research is however, indirectly important to the firm, since the resulting basic knowledge may be used in the production of more applicable technical knowledge.

In reference to the definitions cited above, applied research is most closely associated with technological change, since it is aimed at producing new practical knowledge. Development expenditure, according to the official definition, is concerned with the use of such knowledge for specific production purposes. The official definitions however, leave some doubt as to where applied research activities end and developmental activities begin. Both seem to be directed toward practical goals.

If we go beyond the official definitions and examine the objectives of the two types of expenditures more closely, the distinction between development and applied research can be strengthened. Taylor and Silbertson (1973, p.61), in their comprehensive study of the U.K. patenting /

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1. Official statistics show the total expenditure on R & D carried out by private industry to be broken down as follows: 3.4% on basic research, 18.9% on applied research and 77.7% on development. See Bowles (1981, p.99, table 3).

patenting system, explain the difference as follows:

> ... these activities are usually fairly distinct, even though they frequently take place in the same establishment. Research is generally distinguishable in practice as being work directed to the discovery of the principles of a new product or process, including the construction of small-scale mock-ups or working models, while development comprises the conversion of principles, formulae or models into saleable products or commercially-viable processes.

It is clear that the expected outcomes of applied research and development activities differ. Applied research is expected to result in what may be labelled invention; development in innovation. Development expenditure is not in principle an input in the production of technical knowledge; rather it occurs after the new knowledge is produced. In practice however, additional knowledge may be created while products or processes are being developed for commercial uses, even if this is not the primary objective of the development phase. This seems likely to occur especially in the case of minor improvements to products and processes, as opposed to major discoveries.

Invention and Innovation Applied research, as mentioned above, results in invention, which most economists define as the creation of new technical knowledge. Taylor and Silberston (1973) stress that inventions are new technical possibilities which may or may not develop into actual commercial use. They (Taylor and Silberston, 1973, p.27) define invention as:

the /

> the creation of 'potential' new products or processes, i.e., designs, specifications or models that embody the essential working principles of useful technological discoveries.

Taylor and Silberston (1973, p.27) distinguish invention from innovation, which according to them is:

> ... a general term to refer to the whole process of converting inventions into full-scale production operations including investment in new plant and equipment for the purpose.

It should be recognised however, that there is not always a tidy separation between the two activities of invention and innovation. In fact some economists argue that the two activities should not be separated from an analytical standpoint. For example Langrish, et. al. (1972, p.7) view the two as 'inextricably interlinked because they stand in a mixed causal relationship' innovation resulting from invention and invention itself from the process of commercialisation of ideas. Parker (1974) agrees with this analysis, seeing the two activities becoming more closely associated as corporate rather than individual invention becomes more and more important.

In this thesis we shall use the Taylor and Silberston definitions, separating invention or the creation of new technical knowledge from innovation or the first use of the knowledge in a commercial venture. This is partially because /

because it is felt that the two activities can be separated in principle. Certainly not all inventions are commercially exploited, as the definition states, they merely have the potential to become new products or processes. When new technical knowledge is used for innovation purposes, it may be only after a considerable lag-time representing the development stage. Also, the two processes of invention and innovation may require quite different skills. Pavitt and Soete (1980) suggest that innovative activities involve corporate strategy, production and marketing skills and professional competence beyond the laboratory and patenting department.

Product and Process Inventions This thesis in concentrating on the generation of new technical knowledge will focus on invention. In order to be consistent with our previous distinction between a firm's product and process technologies, the distinction between a product and process invention will also be made. A process invention is defined here as one which potentially reduces the inventing firm's costs of production. A product invention, on the other hand, may potentially be converted into a new or improved product with the aim of increasing the firm's market share or moving it into an entirely new market.

In practice the distinction between process and product inventions may become blurred and in some cases arbitrary. For example, it may be that a new process which reduces the cost of producing a product may also alter it in some way /

way. This problem is faced later in the thesis in the empirical work when patents are classified as either process or product inventions.

It should also be pointed out that a product invention in the capital goods industry, is from an aggregate economic point of view a process invention in that it does not lead to any qualitative change in final goods. However, while this may be true from an aggregate or even an industry viewpoint, from the point of view of the firm, which may be competing on the basis of its product technology, the product distinction is valid.

<u>The Diffusion of New Technical Knowledge</u> Using our definitions, the various steps in a chain leading to the wide use of a new technology can be shown as below:

Research → Invention → Development → Innovation → Diffusion

The last step in the chain, technological diffusion occurs when the new technology spreads in use to firms other than the innovating firm and becomes part of an industry's accepted technology. This diffusion process occurs both for new process knowledge and new product knowledge. A number of factors determine the length of the diffusion stage including patent protection, the ability of firms to imitate or 'invent around' patents, the profitability of the original innovation and the size of investment required to implement the new technology.

Although /

Although the diffusion of new technical knowledge will not be the main concern of this thesis, it is important to demonstrate that the various stages of the chain shown above are related. Firms produce new technical knowledge to use it in profit making ventures. If after inventing and introducing a new product, a firm finds that its competitors can imitate it very quickly, the rate of return to invention and therefore the incentive to invent may be diminished. However, a firm introducing a new product in a capital goods industry, would benefit from its innovation being diffused in the production technology of the using industry very quickly. While invention is the prime concern of this thesis, innovation and diffusion are related and important to our understanding of the inventive process.

1.4 The Measurement of Technological Change

In order to test the theoretical models of technological change developed in this thesis, an adequate measure of new technical knowledge is required. Yet it is difficult to find an accurate measure of something as intangible and as abstract as knowledge.

The measure of technological change chosen for this study is the number of patents accepted from a firm by the U.K. Patent Office over a period just exceeding one year. While the practical procedures followed in assigning patents to firms are outlined later in the chapter on methodology, in this introduction it is useful to discuss the general problems surrounding patent data

as /

as an index of technological change. It is also useful to review alternative measures, which have been used in other studies.

Alternative Measures of Technological Change Initially technological change was measured indirectly or by its effect on productivity growth. Using a production function approach, the residual or the increase in output unexplained by the increases in capital and labour is attributed to technological change. There are many drawbacks to this approach however, as outlined in section 1.2 (see pp. 9-12). From the standpoint of this firm-level study the approach is unsatisfactory because it does not consider the generation of new product technology, which may, if the firm is in the capital goods sector, contribute to another firm's productivity growth.

Two more direct measures of technological change are: (1) R & D expenditures made by a firm or alternatively employees engaged in R & D activity within the firm and; (2) the number of patent applications made by a firm or patents issued to a firm. These are also the two most frequently used measures in firm and industry studies. This is to a large extent due to data availability, although somewhat less information is available in the U.K. than in the U.S.

A potentially superior measure of technological change is a list of a firm's contributions to new technology over a period of time, ideally weighted by some index of their quality. This information however is /

is costly, in terms of resource time, to compile. While a number of U.S. studies have made use of new product introduction as a measure of technological change, such studies have been limited in their industrial scope.

Comanor (1965), in a study of 57 firms in the U.S. pharmaceutical industry, used the number of new products introduced, weighted by sales in the first two years after introduction, as his measure of technological change. In compiling his measure, Comanor gathered information from an industry consultant and a marketing research firm. Others, including Baily (1972) for drugs and Mansfield (1969) for steel, petroleum refining and bituminous coal industries, have used trade associations and professional journals to compile lists of major technological changes made by firms.

In the U.K., the Science Policy Research Unit at the University of Sussex has compiled data concerning over 2000 significant innovations in British industry from 1945 to 1980 (Townsend et al., 1981). The data base however, does not cover invention or incremental innovations made by firms and the authors themselves have some concern over the representativeness of the sample of innovations. Due to limited resources and the intention to evaluate a relatively large number of firms involved in inventive activity across industries, the choice of a measure of technological change in this thesis is narrowed to R & D or patent data.

<u>The Use of R & D Data to Measure Technological Change</u>

Research /

Research and Development expenditure and employment in R & D activities are frequently used measures of technological change, especially in U.S. studies. R & D reflects the flow of inputs into the production of new knowledge, generally undertaken in the industrial research laboratory. In this sense it represents those activities of the firm formally dedicated to technology changes and accounted for as such in its records. The data is likely to underestimate then, technological changes originating on the shop floor as the result of production activity itself. This is however, not so bothersome in a study of large firms as it would be in a study of small firms, where informal inventive activity would be expected to be proportionately greater. It would be important however in a cross-industry study, as industries differ in the extent to which their research activities are formalised in laboratories.

The use of R & D data to measure technological change in this study is problematic both from a practical and theoretical standpoint. In the U.K., although R & D data is collected by the government on a regular basis from firms, the information is published at the two and three digit industry level only. Unfortunately no comprehensive publication of R & D statistics at the firm level is available. In the United States economists have benefitted from the publication of firm level /

level R & D employment data.[1]

It would be possible of course, to compile U.K. firm R & D data from the primary source, using a survey. There is some evidence however, that such surveys do not obtain high cooperation from firms. Schott (1976) for example, surveying the largest 300 U.K. manufacturing firms concerning their applied R & D expenditure, found only 42 per cent cooperating with the survey[2].

Aside from the practical problems of data collection, it is also questionable whether R & D as an input into the knowledge production process is theoretically a good proxy for the output of the process. Industries and firms may differ in their ability to produce new technical knowledge from given amounts of R & D expenditure. Some firms may be more efficient than others in knowledge production. Also the flow of basic knowledge to industries might differ substantially, allowing greater 'technological opportunities' in some industries than others.

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1. Information concerning firms' R & D employees in the U.S. is published in <u>Industrial Research Laboratories in the United States</u> by the National Research Council, National Academy of Sciences.

2. Although the questionnaire's response rate was 59.3 per cent, of the 178 replies, 34 reported that they undertook R & D but would not cooperate with the survey. An additional 17 firms did not complete questions related to the size of R & D activities. Of the 127 firms fully cooperating, another 63 reported no R & D activity (see Schott, 1976, p.81).

The Use of Patent Data to Measure Technological Change

The number of patents registered by a firm is taken in this thesis to be an index of the firm's inventive activity or of its production of new technical knowledge. Although patent statistics have recognised disadvantages, it is argued here, that if interpreted carefully, they can provide a useful index of technological change. It is important to emphasise, as Schmookler (1966) did in his patent based study, that patent statistics are merely an index of inventive activity. No attempt is being made with the patent data to quantify in an absolute sense new technical knowledge produced by firms.

A theoretical advantage of using patented inventions as a measure is that they fit conveniently into our definition of technological change in section 1.3. As Boehm noted (1967, p.124) in his study of the administration of the U.K. patent system: 'Patent law, as part of the law of intellectual property, establishes a property right in technical knowledge.' Although legally complex, the definition of an invention is in its essential characteristic quite clear, according to Boehm (1967, p.125):

> it sets out to ensure that patent protection is available only to technical developments which are new. Newness or novelty is the keystone of the laws' attempt to define invention.

To be accepted as patented inventions, new technical developments must pass two tests; the novelty test -

an /

an inventive step must have occurred; and a relevancy test - the knowledge must apply to a manner of new manufacture. Examples of areas beyond the limits of patent protection are agriculture, horticulture and basic scientific principles, although a method of using a basic scientific principle in manufacture can be patented.

The practical advantage of an available patent data base at the firm level is also a consideration. However, if the deficiencies of patents as a measure of technological change as compared with other measure were significant, the practical advantage could not on its own justify using the measure. It is argued here, that compared with alternative measures, all of which have some disadvantages, patents are an adequate measure for this study. It should be noted that while patent data is available at the firm level, it is by no means easily compiled. A description of the compilation of the patent data base is left to Chapter 7.

Despite the definitional convenience described above, patents as a measure of technological change have serious shortcomings which must be recognised. Two major criticisms of patent statistics are summaried by Boehm (1967, p.138):

> As a measure of inventive activity they are dearly defective - not all inventions are patented and the greatest and the most nugatory of inventions score equally whatever their technological or economic value.

Such /

Such limitations have caused some economists, including Leonard (1971), to regard patents as too unreliable a measure to assess inventive activity. Taylor and Silberston (1973) while acknowledging their usefulness as a rough indicator of inventive activity for some purposes, are doubtful about using them in a statistical analysis of market structure or size of firm on technological performance. Since this is what this study intends to do, the limitations described above must be examined more closely.

Variations in the Propensity to Patent The first critical point made by Boehm, that all inventions are not patented, is important if we regard the number of patents issued to a firm as an index of technological change. A firm may decide that the expense of patenting an invention is not justifiable considering the benefit received. This may be because the invention is not sufficiently valuable in economic terms or because the protection given by a patent is not of sufficient value. The firm may decide not to patent certain knowledge if it fears that disclosure may lead to imitation by competitors. This would be particularly true of in-house inventions which do not appear in the market place and therefore can be kept secret. There is a risk involved however in non-patenting in that the firm has no property right over the new knowledge which it has created.

There is some limited evidence on the extent to which firms regard patents as important protection of their technical knowledge, at least that knowledge which is carried /

carried to the innovation stage. In a U.S. study of industrial patenting and imitation in four industries, Mansfield, Schwartz and Wagner (1981, p.909) found that 70 per cent of the 48 innovations studied were patented. The importance placed on patenting in the U.S. study varied considerably between industries however, with the drug industry regarding patents as most valuable. Patents in the electronic and machinery industries were regarded as of doubtful validity and offering little protection.

In the U.K., Freeman (1974) in his study of success and failure of industrial innovation, found that almost all of the innovators studied, both successful and unsuccessful, took out patents and regarded them as important. Freeman (1974, p.83) in another study used patents to measure innovative activity in the plastics industry, viewing the data as 'more useful than is commonly believed'. He did stress the limitations of patent data however, which include the variation between firms and industries in their 'propensity to patent'.

The variability in the propensity for firms to patent among industries must be considered in a study such as this, which includes firms from an industrial cross-section. Differences in inter-industry patenting propensities can be attributed to a variety of factors. For example, Scherer (1965a, p.1101) attributed the 'profuse' patenting in the chemicals industry to the ease of gaining market positions through 'manipulated molecule' patenting. The drug industry as sub-

component /

component of the chemicals industry seems particularly prone to such profuse patenting, although the threat of imitation along with the objective of a higher market share seems a likely cause.

Pavitt and Soete (1980) while referring to innovative activity rather than inventive activity, find that patent data appear to underestimate innovative activity in aerospace and motor vehicles just as R & D statistics provide an underestimate in mechanical engineering and in fabricated metals.[1] With regard to aerospace, Scherer (1965a) notes that aircraft makers and other defense specialists seldom seek patent protection on inventions made under government contract since they are obliged to extend either exclusive rights or at least a royalty-free license to the purchaser. On the other hand, R & D expenditure may underestimate technological changes in industries lacking formal R & D laboratories, such as fabricated metals and mechanical engineering, whereas patent data pick up informal inventive effort.

Although the variability in the propensity to patent among industries is troublesome, it is by no means disastrous for our study. As Scherer (1965a) points out, empirically the inter-industry variation in the propensity to patent can be viewed as a random disturbance, unless of course it is correlated with an independent variable. It /

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1. This thesis later, in Chapter 8, challenges the Pavitt and Soete assertion with regard to motor vehicle patenting.

It therefore imparts no bias in an empirical study, but does increase the unexplained variance in patenting activity among firms. It is important however, to recognise the possible correlation which Scherer suggests.

The propensity to patent may also vary with firm size and vary for types of inventions made by a firm, whether product or process. Taylor and Silbertson (1973) argue that there are reasons to expect that the propensity to patent to be inversely related to firm size. They suggest that large firms may patent less per unit of R & D (or sales) than small firms in the same field, because the former's R & D programmes include a higher proportion of non-patentable work in development. They add that the complex R & D projects undertaken by large firms require larger inputs per patentable invention for technical reasons. Furthermore, Comanor and Scherer (1969) found in a U.S. study that small firms had a greater propensity to patent than large firms, who could rely on their market and technological dominance to protect their innovations.

Another plausible hypothesis is that the propensity to patent is greater for new product knowledge than new process knowledge. This, in fact, is the finding of Comanor and Scherer (1969) in the U.S. Processes can be more adequately protected by industrial secrecy than products which are disclosed when they reach the market place. This dichotomy is important to this study which separates the two types of inventions and must be recognised in /

in the empirical analysis to follow.

Another consideration is the proneness of patent data to variation over time. Due to secular trends in the data, Mueller (1966) argued against the use of patents in time series analysis. He was encouraging however, of their use in cross-sectional analysis providing the data were averaged over 3-5 years to account for short-term fluctuations. Because of limited resources for the compilation of firm patent data, this cross-sectional study covers a shorter period of time than that recommended by Mueller. Our chosen period however, can be broken down into two shorter sub-periods to give us a check on fluctuations in patenting activity among selected firms.

Varying Patent Quality In this study the inventive activity of a firm is represented by the number of patent specifications accepted by the U.K. patent office from the firm over a little more than one year. Thus the second point made by Boehm in his criticism of the use of patent data is applicable to this study; that is that every patent is given equal weight regardless of the technological or economic value of the invention. Patents which open up entirely new technologies and those whose significance is trivial are weighted equally.

Norris and Vaizey (1973, p.38) list the four possible dimensions of the magnitude of an invention as follows:

A. /

A. Technical past - the magnitude of the technical problem overcome

B. Technical future - number and size of subsequent inventions that follow

C. Economic past of invention - cost of invention in resources

D. Future yield or economic future - discounted present value

Such dimensions however, are extremely difficult to measure. Dimensions A and B would require technical expertise in the relevant area along with some difficult predictions, while C and D would require a substantial amount of economic data. Bosworth (1973) has developed and used at the U.K. aggregate level a measure of the economic value of an invention; that is the number of times a patent is renewed. In this study however, such a measure is prohibited as 4885 patents would have to be traced.

Although the lack of a weighting system is a deficiency, some consolation is gained from the pattern patenting activity actually takes. An analysis of a firm's patents over a period of time is likely to show a cluster of patents rather than a single patent related to any change in a particular production process or product. For example, in this study's patent data base there are five patents from Pilkington Brothers concerning glass fibres to reinforce cement. A patent count therefore gives an index of activity taking place in an inventive area over a period of time, partially picking up B above.

Comanor /

Comanor and Scherer (1969) view the underlying differences in patent value as a random variable, much like the variation in inter-industry propensity to patent. They add that a patent count is not very different from a count of R & D employees which assumes that each employee is of equal value as an inventive input. They (Comanor and Scherer, 1969, p.393) caution however, that the quality of patents might vary so widely that the 'central tendencies would be literally drowned in variance' causing one to question whether results are meaningful or only 'statistical noise'.

Taylor and Silberston (1973) expressing doubts concerning the validity of patent counting as a measure of technological change, warn that patents' variation in economic significance may not be random as between firms of different size. There appears to be no evidence to support this assumption other than findings that R & D per patent increases with firm size. As noted previously, this pattern could be attributed to a number of causes, including inefficiences and lack of formal R & D programes in smaller firms, other than more complex and valuable patenting by large firms. In fact a tentative finding of Sander (1972) in the U.S. was that patent complexity has no relation to firm size.

Comanor and Scherer (1969), in comparing a count of patents from 57 US pharmaceutical firms with two other indices of technological change, attempted to test whether the differences in patent quality overwhelm any association between patents and technological change. They found that both patenting and R & D were correlated with the introduction of new drugs in the 57 firms. In fact a number of studies, including those by Scherer (1965a) and Mueller /

Mueller (1966) have found a significant association between R & D and patenting activity at the firm level. This caused Mueller (1966, p.36) to remark that there appeared to be a 'significant relationship between what goes into the inventive process and what comes out of it.'

Given the findings above and considering the disadvantages and advantages of both measures of technological change, patent statistics are considered to be the best measure for this study. Although this section has pointed to significant drawbacks of the data, if the limitations are recognised and care is taken in analysis, a count of patents issued to a firm should provide a useful measure of inventive activity.

1.5 The Need for Further Study

Given the important economic effects of technological change outlined in this chapter, an interest by economists in the allocation of resources to its production is fully justified. Although a considerable amount of work in the area has been done in the last two decades, including a good deal of empirical work, very little of this has been undertaken in the U.K., using U.K.data. As Kennedy and Thirwall (1972) stated in 1972 in relation to work on technological change in the UK, there has been a lack of research on research. Since that time there have been a few empirical studies, but much more evidence is needed to establish whether or not theories which have been tested successfully using U.S. data are just as valid for the U.K. Also, no previous study has examined the inventive activity of the largest firms in the U.K. as is the intention here.

In /

In addition Schmookler's separation of a firm's product technology from its process technology has been ignored by many undertaking studies of technological change, although this was an important part of his work. This study, by way of contrast, emphasises this distinction both in the theoretical and empirical models developed to explain firm inventive activity.

In the next chapter a brief profile of industrial inventive activity in the U.K. is presented. The Chapter is intended to give an overview of the extent and distribution of both R & D and patenting activity among industries. Chapter three sets the stage for the development of models of inventive activity, by examining the nature of technical knowledge as an economic variable. Here any peculiar features of knowledge are considered with a view to the implications for the allocation of resources to the production of knowledge.

In chapters four and five a review of previous theoretical and empirical work concerning the production of knowledge by the firm is offered. Here, any improvements which can be made in developing our own models will be emphasised.

Chapter six develops theoretical models concerning the firm's decision to undertake inventive activity. Here distinctions between product and process inventions are emphasised. In chapter seven the problems faced in applying the theoretical models to the available data, including patent data, are explained. Chapter eight then /

then reports the results of the empirical tests. Chapter nine evaluates the methodology used in the thesis, particularly with regard to the approach to further study.

CHAPTER TWO

A PROFILE OF TECHNOLOGICAL CHANGE IN U.K. INDUSTRY

Prior to launching a study of the inventive activity of the largest firms in the U.K., it is useful to gain some perspective of the amount of resources devoted to technilogical change, both in the aggregate and among industries. This chapter outlines the major trends in the allocation of resources to new technology, offering comparisons between the U.K. and other western industrialised countries. An assessment of the overall contribution of the largest firms in the country is also presented.

Due to the availability of R&D statistics at the aggregate and industry levels, much use of this data will be made in this profile chapter. The government in the U.K. has compiled and published R&D statistics by two and three digit SIC levels since 1964. The latest survey year for which data is available is 1981; however, at the time of this writing, detailed industry statistics were available only to 1978. The Organisation for Economic Co-operation and Development (OECD) and the European Economic Community's statistical division (Eurostat) are data sources for international R&D comparisons.

Other measures of inventive and innovative activity used in this chapter are patent data, data on employment of scientists and engineers, from the Census of Production, and significant innovations compiled by the Science Policy/

Policy Research Unit, University of Sussex. A source of patent data for international comparisons is the U.S. Office of Technological Assessment and Forecast which publishes U.S. patent data, by country of origin and by industry.

2.1 Aggregate R&D Expenditure in the U.K.

Despite the measurement difficulties outlined in the last chapter, aggregate R & D statistics give us some perspective of the total amount of organised effort devoted to technological change. According to official estimates, research and development expenditure in the U.K. accounted for approximtely 2.3 per cent of GDP in the latest survey year, 1981.[1] This percentage, as shown in Table 2.1a below, has returned to the level achieved in the 1960's after falling in the early to mid 1970's.[2] It should be noted that in 1972, the survey year most relevant to our study,[3] there was a drop in real R&D expenditure over the previous year of 1969. This trend continued in 1975, but since 1978 a significant upturn in real expenditure on R&D is evident

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1 The figure here refers to R&D expenditure in the fields of science and technology and excludes the social sciences and the humanities.

2 Since the percentages in Table 2.1a are calculated using current-priced data, changes in them may reflect the effects of relative price movements in R&D compared with general price movements. The highly labour intensive nature of R & D implies costs rising faster than the general price index over the 1970's.

3 Patent data used in the empirical analysis of this thesis cover acceptances in 1975. If a three to four year lag of patents on R&D is correct, 1972 R & D expenditure is most relevant for our study.

Table 2.1a

Total Expenditure on R&D in the U.K., 1964 - 81

	1964	1966	1967	1968	1969	1972	1975	1978	1981a
	£ million								
Expenditure at current prices by performer:									
By Government	212	229	238	249	263	337	556	758	1215
By Universities and further education establishments	47	55	62	72	80	115	179	317	na
By industry	489	580	605	639	680	831	1340	2324	3792
By other sectors	20	24	24	26	22	30	66	111	na
Total	768	888	929	986	1045	1313	2151	3510	5815
Expenditure at constant prices[b]									
Government performed	607	593	598	588	584	575	566	511	na
Industry performed	1400	1504	1514	1506	1513	1418	1340	1566	1661
Total[c]	2201	2301	2328	2325	2323	2242	2151	2365	2522
Total Expenditure as a percentage of GDP at market prices	2.32	2.34	2.32	2.28	2.25	2.07	2.06	2.14	2.30

Sources: J.R. Bowles, 'Research and Development Expenditure and Employment in the Seventies', Economic Trends (August 1981), p. 94, Table A.
J.R. Bowles, 'Research and Development: Preliminary Estimates of Expenditure in the United Kingdom in 1981', Economic Trends (September 1983), p. 108, Table A.
'Statistics Industrial Research and Development in the U.K.', British Business (9 December 1983), p. 751, Table 1.
Note: Figures exclude research in the social sciences and humanities and work performed abroad.

[a] Rough preliminary estimates.

[b] Current price data revalued by the U.K. price index of industrial R&D, except for expenditure by the Government from 1970 onwards which was deflated by the Statistical Office of the European Communities' price indices.

[c] Including R&D performed by other sectors.

Table 2.1a shows, in a breakdown of R&D expenditure by performer, that industry spent 6 per cent more in real terms in 1981 over the previous survey year of 1978. The three years to 1978 saw a rise of over 16 per cent, while in the three years to 1975 real industrial R&D expenditure actually fell. Industry in 1981 performed about 56 percent of total R&D. The industrial section shown in Table 2.1a is composed of private industry, the public corporations and the research associations. Private industry accounts for the great majority of expenditure by the industrial section; 89 per cent in 1978 (Bowles, 1981, p. 98).

Not all of the R&D work performed by private industry is internally funded, however. As shown in Table 2.1b, a significant amount, or about 32 per cent, was funded by the government in 1978, down on the goverment's share in 1972. Preliminary 1981 estimates show the percentage of government financed R&D expenditure in private industry to be 34 per cent (see British Business, 9 December 1983, p. 751).

Table 2.1b /

Table 2.1b

Funding of R&D Performed by Private Industry 1972 and 1978

Sector Providing Funds	1972 R&D £ mil	1972 % of Total	1978 R&D £ mil	1978 % of Total
Government	268.0	36.3	662.6	32.2
Universities	-	-	-	-
Public Corporations	8.9	1.2	39.9	1.9
Research Associations	.3	-	-	-
Private Industry	412.6	55.8	1184.5	57.5
Overseas	49.5	6.7	173.9	8.4
Total	739.2[a]	100.0	2061.2[a]	100.0

Sources: J.R.Bowles, 'Research and Development: Expenditure and Employment in the Seventies.' Economic Trends, No. 334 (August 1981), p.98 Table I.

CSO Research and Development Expenditure and Employment (London: HMSO, 1976) p. 8, Table 1A

[a]Figures may not add to totals due to rounding.

Another important breakdown for the purposes of this thesis is the type of R&D work carried out - basic research, applied research or development - particularly by private industry. In 1978 of the total amount of R&D (current expenditure) performed by private industry, 77.7 per cent was allocated to development, 18.9 per cent to applied research and 3.4 per cent to basic research (see Bowles, 1981, p. 99). Corresponding figures (from the same source) for government performed R&D are 53.1 per cent to development, 26.7 per cent to applied research and 17.8 per cent to basic research, with 2.3 per cent unallocated. More recent 1981 estimates show expenditure by private industry on basic and applied research to have/

fallen slightly, with more emphasis placed on development (see British Business, 9 December, 1983, p. 751). Overall, the figures show a concentrated effort in industry's case in developing inventions for commercial exploitation. Although less pronounced, the government also spent a majority of its efforts in the development area.

2.2 Inventive Effort by Private Industry

A brief look at R&D expenditure figures by broad industry group shows electronics, chemicals and aerospace to be the leaders in terms of total spending. Table 2.2a shows, however, that the positions of these three leaders have changed over time. Real expenditure on electronics doubled over the period shown, bringing it up to first place in 1981. In contrast, the volume of spending on aerospace has decreased since 1964, although spending increased over the three years to 1981 so it again leads chemicals. Motor vehicles and other electrical engineering have also experienced a decrease in real R&D spending while mechanical engineering has recovered from a low point in 1972. While R&D employment figures generally confirmed expenditure trends, it is noteworthy that employment in aerospace did not change between 1978 and 1981 (see British Business, 9 December 1983, p. 751).

Table 2.2a/

Table 2.2a

R&D Expenditure by General Industry Group at Constant 1975 Prices for Selected Years, 1964-1981

	£ million			
	1964	1972	1978	1981
All manufactured products	1365	1377	1512	1661
Chemical and Allied Products	197	231	284	277
Mechanical engineering	115	94	118	124
Electronics	222	302	442	511
Other electrical engineering	82	68	69	53
Motor vehicles	100	97	88	80
Aerospace	391	367	285	337
Other manufacturing	260	219	226	173

Sources: Business Statistics Office, 1978 Industrial Research and Development Expenditure and Employment Business Monitor M014 (London: HMSO, 1980), p.5 Table 1.
"Statistics Industrial Research and Development in the U.K." British Business (9 December 1983), p.751 Table 2.

As noted in the previous section, a significant percentage of the R&D undertaken by private industry is financed by the government. Table 2.2b shows that the percentage varies greatly by industry group, with the government making substantial contributions in electronic engineering and in aerospace. Electronics and aerospace are two of the three R&D leaders in terms of industry spending as pointed out from Table 2.2a. Chemicals, the third spending leader, has a negligible contribution by the government. It is also noteworthy that while government funding for aerospace continued to be substantial in 1981, the proportion was down significantly from previous survey years. While mechanical engineering suffered a 10 percentage point drop in the proportion of government funding for R&D from 1964 to 1978, the percentage figure was up again in 1981. This corresponds to a rise in real R&D expenditure for the three years to 1981 (see Table 2.2a).

/Table 2.2b

Table 2.2b

Percentage of R&D Expenditure in Private Industry Financed by the Government in Selected Years 1964-81

	Per cent of Total			
	1964	1972	1978	1981
All manufactured products	36	37	37	34
Chemicals and allied products	1	1	-	1
Mechanical Engineering	16	9	6	13
Electridal Engineering (including electronics)	36	41	48	na
Of which: Electronics	48	46	53	50
Motor vehicles	1	1	4	1
Aerospace	84	85	72	68

Sources: Business Statistics Office, 1978 Industrial Research and Development Expenditure and Employment Business Monitor MO14 (London: HMSO, 1980), p.6, Table 3.
"Statistics Industrial Research and Development in the U.K." British Business (9 December 1983) p.751, Table 6.

In order to examine the comparability of the various measures of technological change, the Science Policy Research Unit (SPRU), at the University of Sussex, gathered information from several sources to examine industry shares of innovative activity in 1975. Table 2.2c below, which reproduces the SPRU's work, shows industrial innovative activity as measured by R&D, patenting in the U.K. and U.K. patenting in the U.S. Both total and industry (non-government) financed R&D figures are presented. The sectoral shares of patenting in the U.K. were calculated by the SPRU from data provided by the U.K. Patent Office and required converting from a patent classification system to an industrial classification, based on work by Boehm (1967). The figures for U.K. patenting in the U.S. are from the U.S. Office of Technological Assessment and Forecast.

/The

TABLE 2.2c

Sectoral Shares of Innovative Activity in the U.K. in 1975

Percentages

Sector	Total R & D	Industry Financed R & D	Patenting in the UK	UK Patenting in the US
Pharmaceuticals	6.3	10.8	0.9	5.2
Plastics	2.2	3.5	4.4	3.0
Other Chemicals	9.7	15.2	15.8	13.6
Chemicals & Allied Products	18.2	29.5	21.1	21.8
Machine Tools	0.4	0.7	2.8	1.9
Other Mechanical Engineering	7.7	8.0	23.6	24.2
Mechanical Engineering	8.1	8.7	26.4	26.1
Electronics	21.8	15.0	14.9	10.6
Domestic Appliances	0.5	0.7	0.2	0.7
Other Electrical	4.3	5.3	6.1	6.4
Electrical & Electronics	26.6	21.0	21.2	17.7
Aerospace	22.8	6.9	0.8	3.0
Instruments	2.0	2.6	5.7	7.8
Motor Vehicles	6.9	11.5	4.1	4.1
Shipbuilding	1.3	1.1	0.7	0.4
Metal Goods	0.9	1.3	5.0	7.4
Iron & Steel	2.2	0.5	1.7	0.8
Non-ferrous Metals	0.7	1.0	1.9	0.7
Food, Drink & Tobacco	3.1	6.6	2.0	0.9
Petroleum Products	1.4	2.4	0.6	0.6
Building Materials	1.4	2.3	2.7	2.3
Rubber & Rubber Goods	0.8	1.1	0.3	4.3
Textiles	2.1	3.4	2.8	1.3
Other	1.5	0.1	3.0	0.8
TOTAL	100.0	100.0	100.0	100.0

Source: J. Townsend et.al., Science and Technology Indicators for the UK (Sussex: Science Policy Research Unit, 1981) p.101, Table 11.1.

The two patenting measures presented in Table 2.2c were found to have a correlation coefficient of .95 which is significant at the one per cent level. The correlation coefficients of total R&D with the two patenting measures are low: .41 for U.S. patent shares and .42 for British patent shares, both significant at five per cent (Townsend, 1981, p. 102). The rather low correlation, however, may be due to the difficult task of converting the patent classification scheme to an industrial classification scheme. We shall return to this point later when looking at the Boehm conversion system in more detail.

It should be noted from Table 2.2c that, once again, the three leaders in terms of total R&D funding are electrical and electronic engineering, aerospace and chemicals. As expected, the sectoral share of aerospace declines once government is excluded as does electrical and electronic engineering, but to a lesser extent.

Somewhat surprising is the high share of mechanical engineering of total patenting and the much lower share of the sector in total R&D. This is also true, but less pronounced for both instruments and metal goods. The authors suggest the importance of small firms in these industries, which rely to much less an extent on formal R&D programmes, as an explanation for the deviations.

Another notable divergence in Table 2.2c is the higher sector share of innovative activity in motor vehicles when R&D is used as a measure as opposed to when patenting is used as a measure. These results, however, might be /attributable

attributable to the difficulties in converting the patent classification to an industrial classification, which, as will be emphasised later, is particularly troublesome for the motor vehicle industry. Likewise, the much higher share of pharmaceuticals in R&D than in patenting could be due to patent classification difficulties within the chemical industry. Reports of the importance of patents to firms within the drug industry (Mansfield, Schwartz and Wagner, 1981) make the low share of patenting in the table particularly hard to accept. Also notable is the much higher share of patenting in the U.S. by the British pharmaceutical industry.

A further indicator of importance, from the standpoint of this thesis, is some measure of the research intensity among industries. Such a measure is presented in Table 2.2d, which shows R&D expenditure as a percentage of sales for general industrial categories and for selected industries which have high research intensities.

Table 2.2d shows that the three industry leaders in terms of total R&D are also highly research intensive when their R&D expenditure is measured against sales. Chemicals, electrical and electronic engineering and aerospace along with scientific instruments have high R&D to sales ratios. The percentages for scientific instruments decline, however, over the time period shown, as do those for aerospace. Again, the figures for aerospace point to the heavy dependence on government funding of R&D. Within general categories those highly research intensive/

Table 2.2d

R&D as a Percentage of Sales in Selected Manufacturing Industries 1972, 1978

	1972		1978	
	Total R&D	Company Funded R&D	Total R&D	Company Funded R&D
ALL MANUFACTURING	1.53	0.99	1.61	1.12
Food, drink, tobacco	0.29	0.29	0.34	0.34
Chemical & allied products	2.45	2.44	2.24	2.23
Pharmaceutical products	8.12	8.12	10.38	10.38
Synthetic rubber, resins and plastics	2.66	2.66	1.79	1.79
Other chemicals	2.10	2.06	2.07	2.05
Iron and steel	0.46	0.46	0.46	0.45
Non-ferrous metals	0.47	0.46	0.34	0.34
Mechanical Engineering	0.80	0.75	0.93	0.93
Scientific instruments	3.12	2.33	1.85	1.58
Electrical Engineering	5.07	3.02	7.18	3.80
Electronic computers	10.32	7.06	16.08	13.18
Electronic components including tele-communications	8.00	4.13	12.06	4.80
Ships and marine engines	0.85	0.85	0.91	0.57
Motor vehicles	1.49	1.49	1.45	1.40
Aerospace	21.13	4.02	18.52	5.73
Metal goods not elsewhere specified	0.28	0.28	0.28	0.27
Textiles and man-made fibres	0.40	0.40	0.39	0.39
Leather, leather goods and fur clothing and footwear	0.03	0.03	0.04	0.04
Building materials and abrasives	0.38	0.38	0.42	0.42
Pottery, china and glass	1.40	1.40	1.02	1.02
Timber and furniture	0.03	0.03	0.02	0.02
Paper, paper products and publishing	0.16	0.16	0.15	0.15
Rubber and rubber goods	0.83	0.82	0.84	0.84
Other manufactures	0.54	0.50	0.84	0.83

Sources: Business Statistics Office, 1978 Industrial Research and Development Expenditure and Employment, Business Monitor MO14 (London: HMSO, 1979), p.25, Table 19.
Business Statistics Office, 1975 Industrial Research and Development Expenditure and Employment, Business Monitor MO 14 (London: HMSO 1980), p.27, Table 19.

intensive industries of pharmaceuticals, electronic computers and electronic components become even more so over the period shown. The increases in intensity are especially pronounced in the two electronic industries for total R&D, which includes government funds.

The motor vehicle industry which had a significant share of R&D expenditure in Table 2.2c also has an above average research intensity if only company funded R&D is counted. Mechanical engineering, which also scored well, especially in shares of total patents in Table 2.2c, has a research intensity below average for all manufacturing industries as does the metal goods industry.

Another indicator of inventive activity or the technological bias of an industry is the proportion of employees who are scientists and engineers. As stated by Bosworth (1981), persons with such qualifications may be employed not only in R&D laboratories, but also in on going production, in the installation and testing of new techniques and equipment and in advertising and marketing. The latest available data in this area is from the 1971 census of production. It is broken down by three digit SIC classes and is used later in this thesis in the empirical analysis. Here, in Table 2.2e, industries which have high densities of scientists and engineers are presented in order of density. Again, industries in the general categories of chemicals and electronics dominate.

Table 2.2e/

Table 2.2e

Density of QSEs[a] in High Density Industries 1971

Industry	Number per 100 Employees
Electronic Computers	13.20
General Chemicals	8.46
Dyestuffs & Pigments	7.43
Fertilisers	7.12
Pharmaceuticals	6.05
Soups and Detergents	5.92
Synthetic Resins and Plastics	5.70
Radio and Electronic Components	4.57
Aerospace Equipment	4.47
Scientific and Industrial Instruments	4.13
Industrial Process Plant Engineering	3.65

Source: Department of Industry, Persons with Qualifications in Engineering Science Technology, Studies in Technological Manpower No. 5 (London: HMSO, 1976), Table 1.
Office of Population, Census 1971 Great Britain, Part 4 (London: HMSO, 1975), pp.246-251, Table 34.

[a]QSE: Person holding a first qualification at degree level or above in engineering, technology or science.

2.3 International Comparisons

Research and Development spending has a similar impact on the U.K. economy as it does on that of her major international rivals. If total R&D spending is taken as a percentage of GDP, the figures obtained for the European Economic Community, the United States and Japan are around 1.8%, 2.4% and 2.0% respectively for 1977 (Eurostat, 1982, p.57). As seen in Table 2.1a, Britain has a percentage of about 2.3, up from 2.1% in the 1970's.

A similar pattern exists if we concentrate only on R&D expenditure in manufacturing industry. Table 2.3a shows the U.K. second only to the U.S. in manufacturing research/

TABLE 2.3a

Trends in OECD Countries' R & D Expenditure in Manufacturing Industry as a Percentage of Manufacturing Domestic Product

	Total R & D expenditure in Mfg. industry as % of domestic product of mfg.							R & D financed by Mfg. industry as a % of domestic product of mfg.						
	1964	1967	1969	1971	1972	1973	1975	1964	1967	1969	1971	1972	1973	1975
Belgium		2.12	1.92	2.18		2.34					1.93		2.12	
Canada		2.12	2.05	2.13		1.72	1.83		1.77	1.65	1.68	1.31		1.47
F R Germany		2.66	2.64	3.02		2.83	3.28		2.23	2.30	2.60		2.34	2.72
Japan[a]		2.40	2.72	3.06	3.20	3.09			2.38	2.70	3.00	3.13	3.01	
Netherlands			3.85	3.86	3.88	3.48	3.92			3.53	3.47	3.52	3.14	3.55
Sweden		3.41	2.95	3.58		3.62	3.80		2.74	2.52	3.07		3.02	3.21
United Kingdom	4.64	5.06	4.97		4.50		4.56	2.82	3.27	3.04		2.59		2.74
USA[b]		7.11	6.89	6.69	6.43	6.24	6.52		3.53	3.77	3.95	3.80	3.83	4.15

Source: Keith Pavitt and Luc Soete, 'Innovative Activities and Export Shares: Some Comparisons between Industries and Countries,' in Pavitt (ed), Technical Innovation and British Economic Performance (London: The Macmillan Press Ltd, 1980) pp.60-61, Table 3.7.

[a]Assumes foreign funding is negligible

[b]No foreign funding

research intensity. If, however, we isolate R&D expenditure financed by manufacturing industry itself, a different picture emerges. The U.K. falls to fifth place in the table above only Belgium and Canada and equivalent to Germany. The two different patterns point to the comparative importance of government funding of industrial R&D in the U.K. Table 2.3a shows also the superior position of the U.K. in terms of R&D financed by manufacturing industry in the 1960's as compared to the 1970's. The increase in research intensity of Japan over the period is also notable.

Table 2.3a points to the importance of government financed R&D in manufacturing in the U.K. as compared to other countries. In fact, like the U.S., the government in the U.K. funded more than 30 per cent of industry performed R&D. In 1977, the comparable percentages for other OECD countries were: 20-30 for France and Norway; 10-20 for Canada, Germany, Italy and Sweden; and under 5 in Japan, the Netherlands and Switzerland (Pavitt, 1981, p. 104).

Unlike most other OECD countries, government funding has had a strong influence on the pattern of R&D spending in British industry. In the U.K., such funds have been concentrated in the aerospace and electronics industry. Some have argued (for example, Kaldor, 1981) that the large scale British commitment to defence orientated R&D is an integral part of the U.K.'s industrial decline. On the other hand, it is also commonly argued that the huge/

huge expenditure on R&D in the defence industry in the U.S. has aided technological change in other industries, such as the computer industry. We will not deal with this question further except to note that a higher proportion of U.K. government R&D funds go to defence than any other EEC country (see Pavitt, 1980, p.45).

Although the U.K. retains a respectable ratio of R&D spending to total GDP, its share of total industrial R&D spending by all western industrialised countries has declined. Table 2.3b shows the shares of selected OECD countries in total and industry financed OECD industrial R&D. The U.K.'s share decline in industry financed R&D is more severe than its decline in total R&D spending. Among the U.K. industries shown, only chemicals, by a slight margin, and aerospace, by a wider margin, increased their shares. During the time period, the U.S. shares also declined, while those of Japan and Germany rose.

Table 2.3b/

Table 2.3b

Shares in OECD Industrial R&D[a] in Selected Countries 1967&75 (percentages)

	Total R&D		Industry Financed R&D	
	1967	1975	1967	1975
United States	62.9	51.4	49.4	45.7
France	6.4	6.9	5.9	6.2
Germany	8.6	11.4	11.6	12.5
Japan	7.3	12.8	11.9	17.3
U.K.	9.7	8.7	10.7	7.6
Aerospace	8.9	11.4		
Electronic, electrical engineering	8.7	7.6		
Chemicals	8.5	8.7		
Other Transport	8.9	6.4		
Machinery	12.6	7.3		
Metals, Metal Products	11.3	7.5		

Source: Keith Pavitt, "Technology in British Industry: a Suitable Case for Improvement." in Charles Carter (ed) Industrial Policy and Innovation (London: Heinemann Ltd, 1981) p.94, Table 7.2.

Figures for foreign country's share of patenting in the U.S., from the U.S. Office of Technological Assessment and Forecast, also show a decline in the U.K. share between 1963 and 1978, and a substantial increase in the Japanese share[1]. Pavitt (1981) who compared ten OECD's countries' share of industrial R&D activity in 1975 with their share of U.S. patenting, found the two measures to have a high significant correlation. He also found this to be the case for the individual sectors

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[1] Pavitt (1981, p. 95) presents figures from the U.S. OTAF which show the U.K. share of U.S. patenting falling from 21% in 1963 to 11% in 1978 and the Japanese share rising from 5% to 28% for the same period.

of chemical, electrical and and electronic engineering and non-electrical machinery. Only in aerospace was the correlation quite low. These results contrast with the low correlation found by the Science Policy Research Unit between the share of industrial R&D among industries in the U.K. and their share of U.K. patenting in the U.S., as previously noted.

2.4 Inventive Effort Among Firms in the U.K.

Research and development expenditure and employment are highly concentrated in a few firms in the U.K. Table 2.4a shows that the largest 100 R&D spenders accounted for 91 per cent of the estimated total of private industrial R&D expenditure in 1978 and 89 per cent of employment. The picture is one of even greater concentration if only government funds for industrial R&D are taken; 76 per cent goes to the largest five spenders.

Table 2.4a

R&D in the 100 Largest Spending Enterprises, 1978

Enterprises with the Largest R&D Expenditure	% of Total Private Industry R&D Spending	% of Total R&D Employment in Industry	% of government R&D Funds for Private Industry
First 5	41	40	76
First 10	52	52	82
First 20	66	63	91
First 50	82	80	96
First 100	91	89	99

Source: Business Statistics Office, 1978 Industrial Research and Development Expendire and Employment, Business Monitor MO14, (London: HMSO, 1980) p. 23, Table 16.

It is also a fact that the majority of R&D is conducted by firms which are large. Table 2.4b breaks down R&D expenditure in private industry by firm size, in terms of the number of employees. It is clear from the Table that the largest firms in the U.K., or those with over 10,000 employees, conduct the greatest share of R&D across all product groups. The importance of the largest firms, however, varies across industries. In chemicals and mechanical engineering a high share of R&D is conducted by medium-sized firms, with 1000-9999 employees. In motor vehicles, electronics and electrical engineering, and aerospace the largest firms dominate.

As noted previously, R&D expenditure data may reflect the technological activities of the largest firms much better than smaller ones due to the lack of formal R&D laboratories in smaller firms. It is essential, therefore, to consider another measure of technological change and its relationship to firm size. Fortunately the Science Policy Research Unit has provided recent data on over 2000 significant innovations in British industry from 1945 to 1980[1]. Their analysis of innovating firms by size is presented in Table 2.4c. The table shows the distribution of significant innovations, grouped in five year periods from 1960-1980, by firm size based on numbers of employees.

Table 2.4c/

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[1] The 2293 innovations, which were identified by industry experts, covered 30 industrial sectors accounting for 58 per cent of manufacturing output in 1975. See Townsend (1981, p.1).

TABLE 2.4b

Percentage of Private Industrial R & D by Size of Employment of Enterprises, 1978

Total number of employees of the enterprise	All Products	Chemicals and allied Products	Mechanical Engnrg.	Elect-tronics	Other Electl. Engnrg.	Motor Vehicles	Aerospace	Other Products
200-499	1	1	2	1	1	-	-	3
500-999	2	3	3	-	2	1	2	2
1,000-4,999	8	16	23	1	5	2	8	12
5,000-9,999	9	13	18	9	-	5	3	15
10,000-19,999	13	21	27	15	13	2	6	12
20,000 and over	66	46	27	74	78	91	81	58
	100	100	100	100	100	100	100	100

Source: Business Statistics Office, Industrial Research and Development Expenditure and Employment, 1978, Business Monitor MO 14 (London: HMSO, 1980), p.22 Table 14.

Table 2.4c shows that throughout the time period, over half of the significant innovations were introduced by large firms of 10,000 or more employees. Also, the largest category of firms replaced medium sized firms as innovators over the time period to some extent. The table also shows very small firms, or those with less than 200 employees, to be responsible for slightly over 10 per cent of the significant innovations in British industry. These results confirm earlier findings by Freeman (1971) on the role of small firms in innovation. Therefore, while the two measures of technological change, R&D and significant innovations, show different patterns as far as small firms are concerned, the predominance of the largest firms is evident from both measures.

Table 2.4c

Percentage of Innovations in each Firm Size Category, Five Year Periods, 1960-80

Number of Employees	1960-64	1965-69	1970-74[a]	1975-80[a]
1-199	11.0	13.0	11.0	12.0
200-499	6.0	7.0	7.0	6.0
500-999	5.0	5.0	4.0	3.0
1,000 - 9,999	27.0	23.0	19.0	13.0
10,000 and over	51.0	52.0	59.0	66.0
	200.0	100.0	100.0	100.0

Source: Townsend et.al., Science and Technology Indicators for the U.K. (Sussex: Science Policy Research Unit, 1981), p.44, Table 5.1.

[a]The figures presented for the 1970's are weighted percentages, assuming the same industrial sectoral mix of innovations as from 1960-70.

A breakdown of significant innovations into industrial sectors shows considerable variation in terms of the size distribution of the innovating firms. As shown in Table 2.4d, large firms are comparatively strong in most chemical sectors, industrial plant, electronic and electrical equipment other than electronic capital goods and in the process industries of cement, glass and food. It is notable that medium-sized firms introduce fewer significant innovations in chemicals than their R&D share (from Table 2.4b) would suggest. They are the strongest group, however, in machine tools, mining machinery and broadcasting equipment. Small firms contribute large shares of innovations in the mechanical engineering industries, instruments, leather and footwear and electronic capital goods.

2.5 Summary

It is clear that a study of the technological changes made by industry is timely, given Britain's falling share of international research and development and patenting. While the U.K. has maintained a position comparable to her rivals in the percentage of total resources devoted to R&D, the percentage of resources devoted by manufacturing industry itself to technological change fell behind other countries during the 1970's. While government R&D funding for manufacturing industry is comparatively high, in the UK it only impacts upon electronics and aerospace.

The published data available to us indicate that the generation of new technology is highly concentrated in the

TABLE 2.4d

Distribution of Innovations by Firm Size in Thirty Sectors 1945-1980

Product Group	Small 1-999 employees %	Medium 1000-9999 employees %	Large Over 10,000 employees %
Food	17.0	10.8	72.3
General Chemicals	16.7	16.7	66.7
Pharmaceuticals	2.4	15.9	81.7
Detergents	20.0	5.0	75.0
Plastics	12.9	11.4	75.7
Dyestuffs	15.7	5.9	78.4
Other Chemicals	52.7	0.0	47.4
Iron & Steel	5.1	28.3	66.7
Aluminium	2.6	38.5	59.0
Machine Tools	16.4	44.8	38.8
Textile Machinery	52.2	20.3	27.5
Mining Machinery	27.6	40.5	31.9
Space-heating Machinery	52.7	36.8	10.5
Other Machinery	41.5	21.5	36.9
Industrial Plant	0.0	9.1	90.9
Instruments	43.3	18.9	37.8
Electronic Components	12.8	14.7	72.5
Broadcasting Equipment	16.7	45.8	37.5
Electronic Computers	16.7	16.7	66.7
Electronic Capital Goods	31.1	12.2	56.7
Other Electrical	7.7	7.7	84.6
Shipbuilding	3.9	45.1	51.0
Tractors	12.1	7.9	78.9
Motor Vehicles	9.1	24.7	66.2
Textiles	13.7	31.8	54.5
Leather & Footwear	65.8	20.0	14.3
Glass	0.0	17.5	82.5
Cement	4.5	4.5	90.9
Paper & Board	30.9	24.1	44.8
Plastic Products	20.1	20.0	60.0

Source: Townsend et.al., Science and Technology Indicators for the U.K. (Sussex: Science Policy Research Unit, 1981), p.46, Table 5.2.

research intensive industries of electronics, chemicals and aerospace in the U.K. If patent data, rather than R&D data, is used as an indicator of technological change, then the mechanical engineering industry also appears strong. The Chapter also shows that industrial R&D is undertaken predominantly by a few firms which are large. While small and medium-sized firms make notable contributions to the significant innovations, here also it is the large firms which dominate. There is some justification, therefore, for an examination of the inventive activity of the largest firms in the U.K.

CHAPTER THREE

THE NATURE OF TECHNICAL KNOWLEDGE

Knowledge, an unusual economic variable in many respects, can be considered both an output and an input. It is an output of the firm's research and development process and in turn an input into its production process. If a theoretical model of the generation of technical knowledge by the firm is to be developed, it is essential to examine some of the peculiar characteristics of knowledge as an economic commodity. Particularly we shall want to question whether or not these characteristics have an impact on the incentive for firms to produce this intangible commodity.

Inquiries into the nature of knowledge as an economic good owe a debt to Arrow (1971), who examined the allocation of resources to invention from a welfare economics perspective. Arrow argued that due to the peculiarities of knowledge as a commodity, the competitive system failed to achieve an optimal allocation of resources to inventive activity. The peculiarities noted by Arrow (1971, p.164) of 'indivisibility, inappropriability and uncertainty' led him to predict a downward bias in the amount of resources devoted to producing knowledge.

This chapter reviews the peculiar characteristics of knowledge put forth by Arrow, considering their contribution to an underinvestment in knowledge production. Some analysis is provided of the extent the attributes actually apply /

apply to the new technical knowledge produced by firms. A discussion of the methods devised both by the state and by firms themselves to cope with the difficulties surrounding inventive activity is also included. Of interest here is whether the difficulties involved in knowledge production affect the types of firms, in terms of size and market structure, likely to invent. The chapter is concluded with a discussion of the allocation of resources to inventive activity. Here Arrow's characteristics leading to underinvestment in invention are weighed against forces providing for the possibility of overinvestment. Throughout the chapter, justifications for government intervention in industrial inventive activity are considered.

3.1 The Indivisibility Argument

A commodity is said to be characterised by 'indivisibilities' or 'lumpiness' if once produced its services are indivisible among users. Though such goods as bridges and roads are expensive to produce, they have marginal user costs which are negligible. An optimal allocation of resources to such goods therefore, calls for a price of zero and unlimited distribution. Because these conditions prevent the private sector from adequately allocating resources to their production, goods possessing the indivisibility characteristic are known as public goods.

It has been argued that knowledge, as an economic commodity, exhibits the same 'indivisibility' characteristic as /

as described above. Arrow (1971, p.170), who views research and invention as devoted to the production of information, asserts that '... a given piece of information is by definition an indivisible commodity.' While generally expensive to produce, once obtained, information is relatively easy for others to assimilate. Therefore, the duplication or transfer of knowledge can occur at very low social cost. In this respect Usher (1964, p.279) likened knowledge to '...a road broad enough to accommodate any amount of traffic without congestion and durable enough never to be in need of repair.'

The indivisibility characteristic leads to the classic resource allocation problem with respect to knowledge production. Arrow (1971, p.172) summarised the situation as follows:

> ... any information obtained, say a new method of production, should, from the welfare point of view, be available free of charge (apart from the cost of transmitting information.) This insures optimal utilisation of the information but of course provides no incentive for investment in research.

Arrow added (1971, p.172):

> In an ideal socialist economy, the reward for invention would be completely separated from any charge to the users of the information. In a free-enterprise economy, inventive activity is supported by using the invention to create property rights; precisely to the extent that it is successful, there is an underutilization of the information.

The lumpiness of knowledge therefore caused Arrow to suggest a role for the state or a non-profit organisation in /

in its generation and dissemination.

The indivisibility argument, as it relates to technical knowledge however, may be overstated. As Nordhaus (1969a) points out, the transfer costs of technology are not as low as usually supposed. While the transmission cost of information may be very low, the costs of absorbing technology in a production process could require a considerable amount of resources. Knowledge may be embodied in particular labour skills or in capital equipment which must be purchased or developed by firms. In this respect the low marginal costs of information transfer may be less valid for technical knowledge than for general knowledge.

3.2 The Inappropriability Argument

An added problem for the producers of new technical knowledge is the difficulty in appropriating all of the benefits from it. This is because the external economies associated with an intangible item such as knowledge are hard to contain. While the patent system and the technological lead-time gained by innovators help alleviate the appropriability problem, the typical invention remains only partially appropriable. This tends to aggravate the problem of market underinvestment in knowledge described in the last section.

Benefits to Imitators The generation of new technology bestows external benefits on firms other than the knowledge generating firm, who are able to use or imitate the new technology in their own production processes and products. The /

The value added by the new knowledge for its producer is therefore reduced, in turn reducing the incentive to invent. In fact, as Taylor and Silberston (1973) note, there may be a disincentive, since copying firms would be in a superior position to the inventor, obtaining the benefits of the new technology without the costs of producing it. This argument relies on the low transfer costs of knowledge, explained in the last section.

The 'inappropriability' problem is partially solved by the establishment of legal property rights in new knowledge in the form of a patent system. Under this system, the Crown awards exclusive control over an invention for a period of up to twenty years to the inventor who first discloses it[1]. The patentee acquires the right, enforceable by law, to decide who shall and who shall not use his patented invention.

The patent system however, only partially solves the problem of appropriability, since competitors can and do 'invent around' or imitate patented inventions. The inadequacies of the legal property right over knowledge are described by Arrow (1971, p.170) as follows:

> However, no amount of legal protection can make a thoroughly appropriable commodity of something so intangible as information. The very use of information in any productive way is bound to reveal it, at least in part. Mobility of personnel among firms provides a way of spreading information. Legally imposed property rights can provide only a partial barrier, since there are obviously enormous difficulties in defining in any sharp way an item of information and differentiating it from other similar sounding items

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1. The length of time for which a patent can be awarded and renewed was increased in 1981 from 16 to 20 years. A prime argument in favour of the extension was to increase appropriability.

Demsetz (1969) however, is not as pessimistic about the possibilities of appropriating the value of information through the patent system as Arrow. He suggests that the extent of appropriation would be increased by increasing resources for policing patent infringements. While acknowledging that all theft of information cannot be eliminated at reasonable costs, he argues that knowledge is not a unique asset in this respect.

Patent protection is now, however, the only means by which firms may appropriate the benefits of their inventions. As noted by Matthews (1973), the position of technological leadership gained by the innovating firm before rivals are able to imitate, is more important in most cases than patent protection. Due to lags and frictions in the information transfer process, the rewards for R & D are not competed away instantly. There are however, wide variations in imitation rates among industrial innovations, as reported by Mansfield and others (1977b). This in turn leads to considerable differences in appropriability for inventing and innovating firms. This matter shall be taken up in greater detail after a description of the other external economies surrounding knowledge generation.

Other External Economies Even if a firm producing technical knowledge had no imitators, it is unlikely to be able to internalise the full benefits of its inventions. Substantial benefits are likely to be reaped by the firm's customers, either final consumers or other /

other firms. Mansfield et.al (1977b),p.148) show graphically that a product invention in the capital goods industry may have the effect of lowering prices of the final goods produced by the capital equipment. Alternatively instead of consumers reaping the benefits of the invention, the firm purchasing and using the improved capital good might attempt to reap most of the resulting cost reductions in increased profits.

Mansfield and others (1977b) also show that there are benefits external to the innovating firm for both product innovations sold directly to final consumers and for process innovations used by the innovating firm itself.[1] Consumer product innovations may reduce the cost of a particular household activity such as operating dishwashers. The potential price-reducing benefits of a process innovation reducing costs to the using firm is analogous to the case of the capital goods innovation already noted.

The external benefits described above together with the externalities due to imitation would have to be considered in arriving at a social as opposed to a private rate of return to invention. The social costs of invention /

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1. Treating new product inventions as the archtype of economic progress, Usher (1964) shows through the use of indifference analysis that any commercially profitable invention confers a net benefit on the community as a whole and that some inventions are worth undertaking to the community as a whole even though they are unprofitable under a patent system.

invention and innovation, for example parallel research efforts and uncommercialised research, would also have to be considered. An important empirical finding of Mansfield et al. (1977b, p.157), when they calculated rates of return to 17 industrial innovations in the U.S., was that private rates of return were generally lower than social rates of return. In fact, in about 30 per cent of the cases, the private rate of return was so low that no firm with hindsight would have invested. On the other hand the social rates of return to these innovations was so high that from society's point of view the investment was well worth while. The important point is whether the private returns to invention are high enough relative to alternative investments to induce firms to undertake R & D. As Griliches (1958) notes, the social rate of return to the invention and development of nylon was likely many times higher than the private rate of return; yet profits were high enough to induce DuPont to follow through without a public subsidy.

A further externality which is very difficult to calculate is the role new technology plays in stimulating and prompting further inventive activity. It is often argued that it is not only basic knowledge which acts as an input into the production of technical knowledge, but also technical knowledge itself. Also Usher (1964, p.279) notes that 'most research yields at least some useful by-products that cannot be appropriated', these being /

being due to 'the subtle relations among the branches of research' which cause new knowledge in one area to be unexpectedly helpful in solving problems in another area.

<u>Factors Affecting the Degree of Appropriability</u> The degree to which a firm can appropriate the benefits of the technical knowledge it generates varies considerably depending on the properties of the knowledge itself and the industrial structure the firm operates within. Some technological changes will be more susceptable to imitation than others, reducing the returns to the inventor.

The effect of market structure on the firm's ability to appropriate the rewards of its inventions, and therefore on its incentives to invent, has been the subject of much study and controversy. This is because the effects of market structure on appropriability may be opposing and offsetting. The situation is further complicated by the effect of market structure on other factors (factors other than appropriability), such as lack of competitive incentive, on the inventive activity of firms.

It is argued, on the one-hand that the extent of appropriability is higher in monopolistic or oligopolistic industries than those more closely approximating perfect competition. This is because the external economies associated with the benefits of cost-reduction or product enhancement may be easier to internalise if the firm has a good deal of market power. Rather than consumers benefit from cost reducing inventions in lower prices, the /

the firm may benefit from increased profit margins. Firms with little market power may not have this option. Matthews (1973) cites the competitive industries of agriculture and building as examples of appropriability so low that R & D must be done by those other than the producer; e.g. suppliers or customers, the government or cooperative associations.

On the other hand market structure affects the rate of imitation of new technical knowledge which in turn affects appropriability and the incentive to invent. The effects here are far from straightforward. Obviously the fewer the number of firms in the industry the lower the number of potential copiers. However the strength of response is not determined by numbers alone but also by the degree of technological rivalry, which may be intense among oligopolists. The threat of imitation is further complicated by potential entrants to the industry. We might expect the firm to reduce its inventive activity if its inventions are likely to be copied quickly by rival imitators. Inventing firms can at the same time be imitating firms and the scramble for market shares through technological rivalry may boost the inventive effort of all firms in an industry. The effect of market structure on the incentive to invent will be discussed further in following chapters.

Market structure is not the only factor affecting imitation rates. Imitation costs and lags may be higher in some industries than others. Mansfield (1968, 1977), who /

who has undertaken considerable empirical work in the area, has found the range of response to be significant. In a simple model of the imitation of process inventions, Mansfield et al. (1977b), cite prime determinants of rapid imitation to be high profitability and a low required level of investment. These factors were also important to the speed of imitation of product innovations, together with the existence of patents, the ease of inventing around them and the growth in sales of the product innovation. It is argued that where sales of the innovations are growing rapidly, the chance for an imitator to gain a foothold is enhanced.

Parker (1974, p.49) adds that unless a monopoly exists or a company has a 'watertight patent position, the imitation rate is outside of its control.' This influences the risk involved for a firm in assessing future revenues from its new technology.

Taylor and Silberston (1973) also refer to the strength of the patent position in determining the likelihood of imitation. Regarding the infringement of patents by competitors, they (Taylor and Silberston, 1973, p.20) suggest that 'strong patents or those which are defendable in court as 'novel methods of manufacture' are unlikely to be infringed upon. This is especially true if they are of significant commercial value to the firm, causing it to be wary of copiers. The case is different for weak patents which may not withstand a court test.[1] If these

are /

1. Very few patent disputes actually reach the Court. Like that in other countries, testing of U.K.patents is unofficial, consisting of 'infringement and counter-infringement'. (See Taylor and Silberston, 1973, p.14)

are of commercial value they are more likely to be copied without a protest from the patentee who may not wish the weakness of the patent exposed.

Another factor affecting appropriability is the type of invention, either product or process. To the extent that process inventions are more likely to remain secret than product inventions, whose technical feature are revealed on the market place, one would expect their appropriability to be greater. Matthews (1973) however, disagrees,predicting the benefits of process innovations to be less appropriable than product innovations. Very limited evidence provided by Manfield et al. (1977b, p .160) in this area shows the differences between social and private rates of return to be higher for products than processes, although the difference is not statistically significant.

The degree to which the firm can internalise the benefits of its inventions affects its incentive to invent. Therefore to the extent that degrees of appropriability differ among industries and types of inventions, the allocation of resources to inventive activities may be distorted. Matthews (1973, p.14) states the problem as follows:

> ... the appropriability of the results of R & D varies greatly between different cases. So at least as important as the general underutilisation of resources to R & D as a whole is the likely mis-allocation within R & D between projects of differing degrees of appropriability.

We /

We shall return to this problem of misallocation of R & D funds after reviewing the 'uncertainty' characteristic.

3.3 The Uncertainty Argument

The expenditure by firms on research and development can be viewed very much like an investment decision, with the expectation of a future stream of revenues in exchange for a given capital cost. Therefore, like any other investment decision, the estimation of future expected benefits involves an element of risk. It is argued by a number of economists however, that the risk involved is considerably greater than conventional types of investment in capital equipment. Arrow (1971, p.172) explains that due to its very nature, invention must be looked upon as a very risky business:

> The central economic fact about the processes of invention and research is that they are devoted to the production of information. By the very definition of information, invention must be a risky process, in that the output (information obtained) can never be predicted perfectly from the inputs ...
> Since it is a risky process, there is bound to be some discrimination against investment in inventive and research activities.

Others addressing the problem of uncertainty in R & D activities have stressed the distinction between risk or what Nordhaus (1969a, p.55) describes as 'mild uncertainty' and true uncertainty. Under risky conditions, the firm can calculate estimates of the probability distribution of returns and act accordingly . However under true uncertainty such estimates are unmeasurable. Inventive /

Inventive and innovative activities, it is argued, are likely to be characterised much more by uncertainty than risk.

The Reaction of Firms to the Uncertainty Problem

Available evidence shows that firms deal with uncertainties of invention and innovation by adopting a very cautious approach. They favour projects which are short term and with the objectives of making very small advances in technology. In addition it is often argued that to be induced to undertake more important R & D projects, firms require a very high estimated rate of return.

In order to investigate firm strategies to minimise risk, it is useful to distinguish between the technical uncertainties associated with R & D and the market uncertainties. Technical risks are those associated with successful completion of an R & D project with an output representing new technical knowledge. Market risk is associated with the liklihood of the commercial success of a new technological development. A consensus would agree that market risks prove the more difficult for the firm.

Technical risk depends to a great extent on the complexity and size of the technological development sought. While fundamental research and radical product and process inventions may be characterised by high degrees of technical risks, projects which seek only minor technical improvements are not very risky.

Certainly /

Certainly the available evidence shows that R & D projects undertaken by firms are not characterised by high levels of technical risk. Schott (1976, p.86), in her survey of applied R & D in the largest 300 firms in the U.K., found that 60 per cent of technically successful R & D projects were completed within two years. In the U.S. Gerstenfeld (1970) and Mansfield (1968) also found project completion times to be low. Schott comments that while the short-term nature of R & D makes the likelihood of radical new innovations small, the cumulative effect of small improvements can be large. Schott's findings are consistent with those of Hamburg (1966, p.71) and Jewkes, Sawers and Stillerman (1969, p.72-88) who in studies of important inventions attributed only 26 per cent and 20 per cent respectively to corporate R & D laboratories.

A number of U.S. studies have examined the expected probability of technical success (prior to project launch) for R & D projects undertaken by firms. Gerstenfeld (1970, p.22) calculated an average probability of success of .71 for 170 firms. Mansfield (1968, p.57) found expected probabilities to be .80 by the project team and over .50 when corrected for the project team's optimistic bias, for seventy R & D projects in one leading U.S. firm[1].

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1. The actual success rate for the 70 projects was 44 per cent, however only 16 per cent of the failures were attributed to technical problems. Most failures were attributed to changes in project objectives and changes in the priorities of the firm.

A more recent study by Mansfield et al. (1977a, p.24) however found the estimated probabilities of technical success for R & D projects to vary greatly among 16 firms.

Parker (1974) argues that technical risk is not an independent variable, but one subject to a good deal of influence on the part of the firm. For example, a firm can decrease the risk of its R & D investment expenditure by diversifying among projects with some statistical independence.[1] A firm might also adopt parallel R & D efforts toward one particular technical problem, raising costs, but increasing the probability of success. These types of risk lowering activities of course, favour the large firms with access to considerable resources for R & D.

Mansfield (1968) however argues that corporate R & D laboratories seldom resort to parallel R & D efforts to lower risks, precisely because the risks they take are so small. As evidence he (Mansfield, 1968, p.60) cites findings concerning 45 R & D projects, showing actual expenditures exceeding budgeted expenditures by 20 per cent only in 15 per cent of the cases. Other work by Mansfield et al (1977a) shows that cost over-runs for R & D projects are greater for new products than product improvements or for riskier types of projects.

It /

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1. Nordhaus (1969, p.56) cautions however that when the distribution of returns to research is highly irregular this result does not hold.

It seems generally accepted that the market risks of R & D are greater than the technical risks assumed by firms. This is because market risks are much more susceptible to outside influence. The reactions of both the firm's competitors and consumers must be predicted far in advance of the market launch of the innovation, if future revenues are to be estimated correctly. There is the further threat of technological obsolescence, cutting off revenues abruptly. Schott (1976, p.89) found that virtually all innovations of large U.K. firms were regarded as obsolete by their twentieth year and 36 per cent between their fifth and tenth year. She found product obsolescence to occur more readily than process obsolescence.

The evidence concerning market risk is much weaker than that concerning technical risks taken by firms. Mansfield et al. (1977a,p.24) find for a small sample of U.S. firms, that the probability of economic success (given commercialisation) for the majority of firms is over .70 for the R & D undertaken. The definition of economic success used here is a rate of return on commercialised R & D over that available on other investment opportunities. In an earlier study by Mansfield (1968, p.59), it was found that the probability of market success of commercialised projects was .40.

Parker (1974) suggests that the actions of firms with respect /

respect to inventive and innovative activity show that management must regard market risks as high.

Few resources are allocated by firms to R & D activities. Table 2.2d in Chapter Two shows that for all manufacturing industry, R & D represents only 1.12 per cent of sales. We have already noted the short term nature of R & D projects and evidence on payback periods shows that these are short also, indicating a preference for non-risky ventures. Gerstenfeld (1970, p.22) in a survey of 170 U.S. firms found the average payback period to be 4.26 years for large firms and 3.50 for others. This suggests that large firms take a slightly longer term view. The rate of return to R & D projects should be expected to be high to induce firms to undertake the riskier types. On profitability there is mixed evidence however, which is difficult to analyze without knowing the importance of the innovations introduced.

A number of studies, for example Mansfield (1968, p.58), show very high rates of return to R & D projects, well over 100 per cent. However, later research by Mansfield et al. (1977b,p.157) shows the median private rate of return to 17 innovations to be about 25 per cent, with much variation and including some very low rates of return. The 17 innovations in the U.S. were described as of average or routine importance, not major breakthroughs.

Another point should be made on the distinction between the risks involved in open-market product innovations and in /

in-house process innovations. While process innovations involve only technical uncertainties, product innovations involve both technical and market uncertainties. This led Freeman (1974, p.227) to conclude that the majority of firms would have 'a powerful incentive most of the time' to avoid radical product innovations, product differentiation and process innovation'.

While the above conclusion might hold for radical new products, the evidence shows that firms spend the majority of their R & D funds on product innovations, although these could conceivably amount to small steps at differentiation. In Schott's survey (1976, p.85) the largest U.K. firms spent 63 per cent of their R & D funds on product innovations and the rest on process innovations. In a U.S. study by Gerstenfeld (1970) the development of new products was overwhelmingly the priority use for R & D funds, followed by the improvement of existing products and the development of new processes. Therefore, despite the extra market risk, product innovations are still looked upon more favourably. According to Parker (1974) this is because management believe that greater impact is made on markets by selling new products than existing products at cheaper prices. He adds that such attitudes show an aversion to price competition and a desire to differentiate products to avoid rivals' encroachment.

Finally, it should be noted that not all firms are risk /

risk-averse. Firms, for example undertaking R & D in biotechnology, are taking very large technical risks as well as market risks, with very high expected rates of return. Freeman (1974, p.237) explains that the risk aversion of entrepreneurs varies significantly with some types more likely to gamble. These include: (a) small-firm innovations; (b) large firms which can diversify their R & D portfolio, thus taking on a few uncertain investments; and (c) large and small firm innovators whose 'animal spirits' lead them on and without realistic estimates of probable returns.

Arrow's Solutions to the Uncertainty Problem Arrow (1971) examined a number of possible solutions to the problem of risk and underinvestment in inventive activities. One solution has already been mentioned. This is the conduct of R & D by large firms who are able to undertake a large number of projects simultaneously, thus lowering risk. This solution was not favoured by Arrow however. An alternative proposal was to separate the act of risk-bearing from invention itself, with investors buying shares in inventors' proposed projects. A difficulty develops here however known as the 'moral hazard', whereby the investors cannot be assured of the best efforts of the non-risk bearer, the inventor. This curtails the shifting of risk; providing an explanation of large internal financing of R & D projects (Kamien and Schwartz, 1982).

Another solution, favoured by Arrow, to the under-investment /

investment problem, is to give the government the responsibility for producing or at least financing the production of technical knowledge. This would provide a more diversified portfolio of investment projects, as with the large firm, but unlike production by the large firm, the new knowledge would tend to get greater use. Demsetz (1969) however, questions whether the government would always be more risk-taking than private enterprise. He argues that in those cases where technological success is synonymous with political success, such as in putting a man on the moon, risky projects would be undertaken. However, in cases where new technology is associated with negative political effects such as unemployment, the government might be more risk averse than private enterprise. It could be counter-argued however, that this latter case might be interpreted as an investment decision based on all private and social costs and benefits, rather than evidence of a risk averse government.

3.4 The Allocation of Resources to Invention

The preceding arguments concerning the indivisibility, inappropriability and uncertainty which characterise technical knowledge[1], lead to the prediction of a downward bias on the part of firms in the allocation of resources to invention. Moreover, within this limited allocation, a further misallocation is predicted, due to differences in the extent of, for example appropriability among industries /

1. The arguments apply even more strongly to general knowledge.

industries, firms and types of R & D projects.

While the patent system is designed to allow for industrial investment in invention, it has been demonstrated that it only provides a partial solution to the problem surrounding the production of technical knowledge by firms. Furthermore with patents differing in importance and ease of infringement between industries, there is no guarantee that it lessons the misallocation problem. As Taylor and Silberston (1973, p.28) explain:

> Implicit in any proper economic defense of the patent system is that it encourages the 'right' amounts and types of innovation, i.e., the right allocation of resources between different types of invention and innovation and between these and other activities in the economy.

Taylor and Silberston add that there are a number of ways that the patent system could encourage misallocation. For example the monopoly benefits of a patent might draw resources away from conventional investment activities and into R & D. It also might encourage wasteful research devoted to inventing around existing patents or divert resources from non-patentable to patentable inventions.

It is possible that the sources of bias leading to an underinvestment in inventive activity will be partially or wholly offset by forces leading to overinvestment. In fact, there are some good arguments supporting an over-investment in technical knowledge production.

Hirschleifer and Riley (1979, p.1405) argue that imperfect /

imperfect property rights in knowledge offset what otherwise might result in an excessive 'rush to invent'. This is due to the 'common property resource nature' of undiscovered knowledge. While many can enter the race for the solution to a technical problem, there is usually only one winner. As Matthews (1973) points out, if the return for being first in a field is large there is potential for overinvestment. And there are few social returns from multiple research efforts, except in cases where there is a large benefit for an earlier solution.

There is also potential for overinvestment in knowledge production due to the nature of competition in certain industries. When firm market shares and profits depend on technological product differentiation, the incentives to invent, innovate and imitate become very high. As with advertising rivalry, the incentive to increase R & D effort in an attempt to increase market share also provides a justification of a continued programme of defensive imitation. As with advertising, the game of technological product rivalry can become self-defeating. When all firms in an industry spend large sums on R & D for this purpose, the net effect becomes somewhat of a 'prisoners's dilemma' in that market shares remain approximately the same and profits are much lower than if firms had agreed to curb R & D spending through cooperation. Technological competition will be addressed in more detail in following Chapters.

These /

These additional considerations with respect to the incentive to invent make any analysis concerning the allocation of resources to R & D more difficult. It is very likely that the strength of counter forces leading to underinvestment and overinvestment in knowledge production differ considerably among industries and types of invention; process, product, risky and non-risky. This suggests that the need for government intervention in private industrial R & D varies greatly among cases. As Matthews (1973, p.30) remarks:

> The idea that non-appropriability and risk call for across-the-board subsidies to R & D is a very crude one; when allowance is made for imperfect competition and other complications, this idea has to be greatly qualified. Hence the need for selectivity in government action.

3.5 Summary

Despite the evidence provided in Chapter two pointing to the importance of large firms in industrial R & D and in the introduction of significant innovations, we should expect the majority of inventions from the corporate R & D laboratory to represent small advances in technical knowledge. This is the result of firms' reaction to risk, an important characteristic of knowledge production. While somewhat abstract as notions, the characteristics of knowledge reviewed in this chapter give important insight into the firm's decision /

decision to invest and what type of R & D projects are supported. Moreover, since factors such as appropriability and risk vary considerably amongst industries and types of projects, they can cause a great deal of 'noise' in any empirical analysis of firm inventive activity. If they cannot be accounted for directly, an awareness of their existence may aid in an understanding of results.

CHAPTER 4

THE THEORY OF FIRM INVENTIVE ACTIVITY

Theories of inventive activity can be classified in a number of ways. A general classification is based on their either exogenous or endogenous view of the development of new technical knowledge. The traditional view of invention was that it was due to individual curiosity and inspiration. This view falls under the exogenous school in the Schumpeterian tradition. Here the supply of inventive output is inelastic with respect to economic variables. It should be emphasised that although Schumpeter has an exogenous view of invention, he viewed innovation as the role of the entrepreneur and very much dependent on economic variables. Because we consider the firm in our analysis to be both inventor and innovator, many of Schumpeter's hypotheses concerning innovators will be considered in this chapter.

More recently, there has been a shift in emphasis to endogenous theories, which attempt to explain invention and innovation as economic phenomena. The endogenous school owes much to Schmookler (1954, 1966, 1972) whose view was that inventive activity was led by the forces of demand. It is under the endogenous approach that the role of the firm as an inventor becomes important, with R & D costs and revenues from inventive effort becoming crucial to inventive decision-making.

In this chapter the theoretical basis for inventive activity /

activity by the firm is reviewed. It begins with a discussion of the Schmookler demand-led theory of invention and proceeds to theories associated with the costs of invention, firm size, market structure, diversification, input costs and the product cycle. In reviewing the theoretical literature previous surveys by Kennedy and Thirwall (1972) and Kamien and Schwartz (1975) were of benefit. A more recent book by Kamien and Schwartz (1982) on innovation and market structure was also helpful.

The chapter, with few exceptions explains the theoretical hypotheses in an informal manner. The discussion is useful however in leading to a more rigorous approach to inventive decision-making by the firm in chapter 6. The chapter also has a relationship to chapter 5, where the empirical results associated with the various hypotheses are presented. The review of empirical studies in chapter 5 follows the same order as we use here for the theoretical review.

The amount of space devoted here to each of the theoretical hypotheses varies considerably depending on the extent to which they have been developed and on their current importance as far as the theoretical literature is concerned. This explains the more extensive coverage of rivalry in R & D and the effect of market structure on invention. The topic of economies of scale in R & D is also covered in some depth because this is important to our later specification of a production function for technical /

technical knowledge.

4.1 The 'Demand-Pull' Hypothesis

Endogenous theories of technological change owe much to Schmookler (1966, 1972), whose general contention was that economic forces, particularly 'the extent of the market', played the leading role in determining the magnitude and direction of inventive activity. Schmookler is thus credited with the 'demand-pull' theory of technological change. It is important to this thesis to review the Schmookler hypothesis in somewhat more detail, especially since it has been subject to some misinterpretation.

Schmookler (1966, p.88), in his major work, explained that every industry had two technologies; its 'product technology' or the technology used in creating and improving products, and its 'production technology' or the technical knowledge used in producing products, which is referred to in this thesis as its 'process technology'. It was process technology with which Schmookler was primarily concerned and which his original demand led theory addressed.

Schmookler questioned whether the decline in invention associated with the process technology of an industry was due to diminishing returns in the production of knowledge (an increase in the cost necessary to obtain a given percentage increase in productivity) or diminishing demand for the final product (a decrease in the value of an increase in productivity). Salter (1960) hypothesised the former; that is over time the inventive potential of /

of a production technology declines. However it was Schmookler's view that the exhaustion of a field's technical possibilities is never approached and that the pattern of changes in industry process technologies is explained by the end result or economic payoff. Technological change therefore slows down in an industry because it becomes less valuable, not because it becomes more costly.

Consistent with his emphasis on process technologies, Schmookler emphasised the capital goods industry in his work. Like Salter (1960) his view was that most improvements in an industry's productivity came about through improvements in the capital goods which it purchased. His testable hypothesis concerned the relationship between the growth in an industry's demand and the level of capital goods inventions associated with the industry's process technology[1].

Schmookler's view that 'the extent of the market' is an important factor influencing invention, is in reference to the market of the industry using the invention. This is revealed in a passage from an earlier Schmookler article (1954, p.187) as follows

> The extent of this market, it is urged here, varied more or less directly with the volume of resources employed, for the greater the volume of employment, the greater the amount of resources that could be saved with a given invention.

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1. Schmookler's empirical work is reviewed in chapter 6.

From the passage above, the connection between inventive activity and market size, which has been so often tested, is clear. It should be emphasised again however, that Schmookler here is referring to the market of the user rather than the producer of inventions.

While Schmookler's emphasis in explaining inventive activity was on demand, he did not neglect supply or the cost of inventing altogether. In this respect he may have been criticised wrongly or at least too strongly. Rosenberg (1974) charges Schmookler with overstating his case for demand-led technological change, interpreting Schmookler to assume a perfectly elastic supply curve of inventions. Rosenberg's (1974, p.100) own view is that while economic forces play a large role in shaping the direction of scientific progress, they are limited by the'constraints of a body of knowledge growing at uneven rates among its component sub-disciplines'. This suggests that at least part of the explanation for the pattern of technological change rests on the supply side.

Schmookler however, did not completely ignore cost differences in explaining inventive activity. In fact he associated their importance with those capital goods industries producing new technical knowledge to be embodied in their products. Schmookler (1966, pp.102-3) states:

> ... it seems reasonable to suppose that while cost differentials evidently have little effect on the number of inventions made to improve a production technology, they may substantially determine which product technologies are tapped to accomplish it.

... /

> ...the hypothesis that each industry's product technology - its array of products - is as improvable as any other's seems untenable.
>
> ...between two rival product technologies, the inventive potential of one may be superior to that of another.

Schmookler therefore did not ignore 'technological opportunity' altogether; it was important to the producer of inventions. We turn to a more detailed discussion of the 'technological push' hypothesis in the next section.

4.2 The 'Technological-Push' Hypothesis

Advance in the underlying basic scientific knowledge associated with an industry is hypothesised to have a major influence on the inventive activity of firms within the industry. This has become well known as the 'technological-push' theory and it is associated with the supply of inventions or the costs of inventive activity. The theory can be traced to Nelson (1959, p.300) who emphasised that demand was not the only factor influencing the decision to invent by an organisation or individual:

> But often, though the inventor believes that there is a great demand for a particular invention, it is not rational for him to attempt the invention, given the state of scientific knowledge.

It has been argued further by Phillips (1966),

Rosenberg /

Rosenberg (1974) and others that technological opportunities differ significantly among industries due to differing rates of growth of scientific knowledge in different fields. The most general distinction is between the 'science based' industries, such as chemicals, electronics, aircraft and scientific instruments; and the traditional industries of primary food, textiles, wood, paper and metal working. In the 'science based' industries the ease of invention is greater and therefore the cost of inventive activity lower.

It is generally acknowledged that the advance of basic science is with few exceptions outside the firm's control. The firm however is able to draw freely, since basic knowledge is by definition unpatentable, on discoveries originating in universities, government and basic research institutes. Technological opportunity is therefore an exogenous variable in the determination of inventive activity by the firm.

While the concept of technological opportunity is reasonable, it is also difficult to define with precision and even more difficult to measure. Evenson and Kislev (1976) go some way towards clarifying the concept in their discussion of the role of applied R & D. They view applied research as filling a gap between basic knowledge and the current level of technology in practice. The larger the gap, the greater the technological opportunities available or the greater the ease of improving a technology. In /

In the Evanson and Kislev model, applied research is a search within a distribution of a random variable. At some point the distribution becomes 'technologically exhausted' unless new basic knowledge can shift the mean or provide new distributions to search. Bailey (1972) also suggested this in his study of the U.S. pharmaceutical industry when he hypothesised that a rapid period of innovation had the effect of depleting technological opportunities for a number of subsequent periods.

It is important to this thesis to emphasise that most supporters of the technological-push hypothesis relate technological opportunity to the product technologies of industries. Phillips (1966) who was one of the early proponents of the theory, Wilson (1977) and Link and Long (1981) all view technological opportunity as the richness of opportunity for new product breakthroughs. Parker (1974, p.76) who also takes this line summarises the situation as follows:

> Industries that are new with a product base which is not yet standardised are able to dip into the veins of unexplored technology to improve their products. They may be science-based in the sense that they may be closely connected to scientific discoveries and thus enjoy a wider range of research options than other industries which do not have such contacts.

The 'technological-push' hypothesis is generally downgraded by those who view demand as the most important impetus to inventive activity. However, a further doubt is /

is raised by those who question the extent to which technological change actually depends on basic scientific knowledge. Norris and Vaizey (1973, p.14) for example challenge the idea that basic scientific knowledge available in the scientific journals leaks into technology, suggesting instead that technology may be subject to 'laws of its own'.

Nelson and Winter (1982, p.119) take a slightly more complex view, distinguishing between a 'cumulative technology' and a 'science-based' technology. They, like Evenson and Kislow, look upon applied R & D as a draw on a general fund of knowledge. In the case of a 'cumulative technology', the firm innovates by making incremental improvements in its own current technique, not by drawing on new knowledge created outside the industry. In the 'science-based' case, the firm's distribution of general knowledge improves over time as a result of events outside the industry, for example advances in fundamental science occurring in universities. It should be noted that the Nelson and Winter study is one of the few who view technological opportunities as applying to a firm's process knowledge.

While remaining somewhat vague, the notion of technological opportunity is an important one. Theoretically it implies that there is an external constraining force on the firm's ability to produce new technical knowledge. It also has important implications for diminishing returns in R & D activity and economies of scale in R & D. We take up some of these implications in the next section on firm size and inventive activity.

4.3 Inventive Activity and Firm Size

As noted in the discussion in section 4.1, the demand-pull theory leads to a hypothesised relationship between inventive activity and firm size. However there are other important influences on inventive activity which make large size an attribute for an inventing firm, particularly on the supply side.

The Galbraith Assertion One influence on the ability of firms to invent is the nature of technology itself, which a number of economists view as changing. Galbraith (1952, pp.91-92) emphasised this point in his much quoted explanation of the decline of cheap technology:

> There is no more pleasant fiction than that technical change is the product of the matchless ingenuity of the small man forced by competition to employ his wits to better his neighbour. Unhappily, it is a fiction. Technical development has long since become the preserve of the scientist and the engineer. Most of the cheap and simple inventions have, to put it bluntly, been made. Not only is development now sophisticated and costly but it must be on a sufficient scale so that successes and failures will in some measure average out... Because development is costly, it follows that it can be carried on only by a firm that has the resources associated with considerable size.

Freeman (1974, p.30), twenty years hence, can be viewed as taking up the Galbraith theme in his discussion of the 'professionalization of R & D'. He explains that the increasingly scientific content of technology is responsible for the removal of experiments from the production /

production line to a separate workshop or pilot plant.

The statements by Galbraith and Freeman imply that there is a 'threshold' level of R & D expenditure which is necessary prior to R & D having any effect. This might be seen in the context of Freeman's work on the electronic capital goods industry. Freeman (1974) explains that in this industry, where competition takes the form of technical innovation and technical service to customers, entry is restricted by R & D capacity. This threshold level of absolute R & D expenditure (not a ratio of sales), is the minimum level needed to defend one's market position. Here defensive R & D entails keeping up to date with the latest discoveries in the field and introducing a continuous flow of product improvements and perhaps a completely new model when necessitated by the competition.

Threshold levels of R & D spending will of course be much greater barriers for industries based on science than in those where the technology is more traditional. As emphasised previously however, the once traditional industries are being invaded by the more scientifically oriented electronic technology. Even in electronics though, as Freeman points out, the 'threshold' is low for some types of electronic instruments, allowing small firms to prosper in this part of the industry.

On the influence of firm size on R & D spending, Scherer (1980) has critised Galbraith as 'guilty of outfictionalizing /

outfictionalizing the fiction writers.' While acknowledging that some R & D projects are beyond the capacity of all but the largest corporations, Scherer describes these as representing the long thin tail of a highly skewed distribution of development projects arranged by cost. He argues that the more numerous smaller projects are well within the means of firms classified as small by current standards. As noted in the last chapter, even the largest firms tend to choose R & D projects which are small, at least as measured by their duration. The point remains however, that in some fields, even small improvements may require a general level of knowledge beyond the acquisition of many smaller firms.

It should also be mentioned that large sums of R & D expenditure may be required to a greater extent at the innovative phase of a project than at the inventive stage. Mansfield et al. (1971) provide figures showing that R & D costs generally weigh most heavily during the post-invention stages, although this varies by industry. This is one reason why the inventions of individuals and in some cases small companies are finally brought to the market by large corporations. As Scherer (1980) notes, the inventions produced by small firms prove attractive assets in merger negotiations. For the small firm however, which seeks to develop its own inventions, the costs of commercialisation may prove a deterrent to invention /

invention itself.

A further point made in the previously cited Galbraith quotation is that large firms have an advantage with respect to the riskiness of inventive activity. As was explained in chapter 3, large firms who are able to undertake a number of independent R & D projects simultaneously can lower their overall risk, as high risk projects are averaged with those of a mundane and low risk nature.

The risk factor has added implications for the financing of inventive activity. If due to the riskiness of R & D compared to other investment opportunities, outside capital is limited, then inventive activity is more likely to occur in firms with sufficient internal funds. The generation of sufficient internal funds to meet R & D thresholds depends on the level of profits the firm is able to realise. While size may be a factor here, so is the degree of concentration existing in the firm's industry. We shall return to a discussion of the influence of concentration on inventive activity later in the chapter.

<u>Returns to Scale in R & D</u> There is some difference of opinion as to whether Schumpeter was more concerned with the relationship between market structure and innovation or size and innovation. Kamien and Schwartz (1982) argue that a careful reading of Schumpeter shows that his main concern was with market structure and that economies /

economies of scale in R & D is more of a Galbraithian theme. Nelson and Winter (1982) argue the opposite stressing that much of Schumpeter's discussion concerned the advantages of large size to innovation.[1] Despite the disagreement there are logical reasons for assuming that increasing returns to scale exist in the production of knowledge. Correctly or incorrectly the argument is generally attributed to Schumpeter.

There are two different 'scales' which may be referred to in discussing the returns to R & D activity. One concerns the effect of the size of the R & D facility itself within a firm of a given size. Another concerns the effect of the overall size of the firm on returns to scale in R & D with an R & D facility of a given size. Kamien and Schwartz (1975) note that the separation of the two effects is important for policy implications. If increasing returns to R & D are related to the size of firms then concentration of sales may be beneficial for technological advance. If however, the economies are related to the R & D facility itself, then this would support the case for cooperative effort in R & D.

One argument in support of scale economies in R & D expenditure is that a large R & D staff operates more efficiently /

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1. Nelson and Winter refer in particular to Schumpeter's <u>Capitalism, Socialism and Democracy</u>, 1952.

efficiently than a small R & D staff. As with technical economies in the production of goods, large R & D operations may be in a position to take advantage of specialised equipment in the research laboratory. Also specialisation of research personnel, which may only be feasible in larger facilities may mean significant efficiency gains. A further source of economies is the increased productivity of researchers when they are able to interact with a larger group of colleagues.

It has also been argued by Fisher and Temin (1973) that an R & D staff of a given size operates more efficiently in a larger firm. This is because R & D projects may benefit from economies of scale associated with other segments of a large firm's operations. There may be pecuniary economies of scale in that larger firms have greater access to capital at lower costs than do small firms. This may be associated with the lower average risks taken by large firms, when conducting a variety of independent R & D projects. Also the per unit costs of distributing and promoting a new or improved product may be lower for large firms. While promotion activities are several stages away from the inventive stage, they can affect R & D decisions since they may determine the profitability of a new product invention.

As with large scale production of goods, a point may be reached where diseconomies of scale in the production of knowledge appear. According to Scherer (1980) this is due to the growing bureaucratisation of the R & D process /

process. This could conceivably be within the research team itself or as part of the overall decision-making process within large firms. R & D projects in large firms may have to be channeled through a chain of decision-making bodies for approval. This both delays R & D projects and adds costs to the R & D operations. Also the inability to get R & D projects approved by management may drive the most original and productive researchers off to start their own ventures.

While the arguments surrounding economies of scale in R & D are logical, they are usually discussed quite informally as above. Fisher and Temin (1973) have generated considerable debate with their claim that incorrect conclusions from empirical tests of the 'Schumperterian hypothesis' have been obscured by the lack of a precise theoretical base for the hypothesis. In particular Fisher and Temin, joined by Kohn and Scott (1982) and Lunn (1982), show that the standard test of proportionality between R & D inputs (expenditure on staff) and firm size is not a test of the Schumpeterian hypothesis which is that the average productivity of R & D inputs increases with both the number of R & D inputs and with the number of non-R & D inputs.

More precisely, Fisher and Temin (1973, p.60) state the Schumpeterian hypothesis as follows:

$$[4.1] \quad F_R > 0$$

$$[4.2] \quad F_N > 0$$

where /

where subscripts denote partial derivitives and where:

$F = F(R,N)$
F = the dollar value of the per worker output of the R & D staff or the average productivity of the R & D staff
R = the number of R & D staff
N = the number of non-R & D staff
$S = R + N$, total firm workers

Continuing, Fisher and Temin argue that [4.1] and [4.2] do not imply what has come to be the standard empirical test of the Schumpeterian hypothesis or:

$$[4.3] \quad S/R \; \partial R/\partial S > 1$$

This is due to the effect of the increase in size of the operating staff on the marginal product of the R & D staff (or $F_N + RF_{RN}$). As explained by Lunn (1982, p.215), if the size of the firm increases, the value of the expected innovation increases (due to $F_N > 0$). This should lead to an increase in R & D spending. But R & D inputs will not increase proportionally because of the shape of the R & D marginal benefit curve, which eventually becomes downward sloping. This is simply diminishing returns to R & D. The higher the level of technology already attained by the firm, the lower the probability that further R & D spending will improve the technology. As Lunn (1982, p.213) notes, if P is the probability of developing an innovation and P is a function of R & D (R), then $P = P(R)$ and $P' > 0$ and $P'' < 0$. Although /

Although the probability of innovating increases with R & D, it does so at a decreasing rate.

The argument above may also be viewed from the point of the production function for knowledge. Scherer (1973, 1980) analyses the situation by examining the two following equations:

$$[4.4] \quad R = \alpha S^{\beta}$$

$$[4.5] \quad A = \gamma R^{\delta}$$

Using our previous notation, the first equation shows the usual empirical test of the Schumpeterian returns to scale hypothesis. The second shows the production function for knowledge with A representing inventive output. Scherer states that the hypothesis testing dilemma of Fisher and Temin disappears if $\delta = 1$ or the knowledge production function is linearly homogeneous. He argues that much empirical evidence on the relationship between R & D inputs and outputs shows this to be the case. Lunn however, disputes this assertion proposing that a stochastic model is a more appropriate version of 4.5 above.

A slightly different analysis of the same problem may be obtained by specifying two inputs to the knowledge production function, R & D (R) and basic scientific knowledge (B) so that:

$$[4.6] \quad A = g(B, R)$$

If basic knowledge is constant or if there are constant technological /

technological opportunities for the firm to draw on, diminishing marginal returns to R & D must eventually set in. However if both inputs are increased proportionately (with exogenous advances in basic science), there may be increasing returns to scale in the size of the R & D operation. The problem here is an input, B, over which the firm has no control and which depends on basic scientific research in government or universities. This is the approach taken in the development of our theoretical models in chapter 6.

4.4 Market Structure and the Incentive to Invent

It has been previously emphasised that some degree of monopoly power and therefore profits from the use of new technical knowledge must be anticipated by the firm if it is to have any incentive to invent. In this section the reverse of the above causal relationship is explored; that is the effect of market power with respect to the firm's current production on its inventive activity. Although the two relationships are separated analytically here, it should be recognised that inventive activity and market power are both endogenous variables.[1] The direction of causation is two-way.

An extensive amount of theoretical work has been done on the effect of market structure on invention and innovation.

It /

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1. Dasputa and Stiglitz (1980) provide a theoretical model in which both market structure and the nature of inventive activity are endogenous.

It stems from Schumpeter's hypothesis[1] that firms in a monopolistic environment are better able to introduce innovations than those in a competitive environment. Therefore society's price for rapid technological change is the static inefficiency associated with a market structure involving large firms with considerable market power.

There are a number of arguments which can be reviewed in support of the Schumpeter hypothesis concerning the effect of market power on technological change undertaken by firms. In some cases however it is difficult to separate those which relate strictly to the market power of firms and those to the size of firms. Although the two characteristics are not strictly dependent and therefore should be analysed separately, they do interact and in practice often appear together.

One argument addressed directly by Schumpeter (1952) concerns the necessity and ability of firms to finance R & D projects from internal funds. Due to the very risky nature of R & D, firms may be unable to attract outside capital. They also may be unwilling to do so due to the disclosures which they would be required to make /

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1. It should be noted again that Schumpeter's hypothesis concerned innovation. It is extended to invention here because we assume the firm to be both inventor and innovator.

make concerning their projects. The argument follows that firms earning supra-normal profits are more likely to generate the required internal funds than those earning only normal profits. The argument is interlinked with the size argument since threshold levels of R & D may require a large absolute volume of profits as well as a high rate of return. Firms with high liquidity are generally large monopolistic firms.

A second but related argument offered by Scherer (1980) is that enterprises earning monopoly profits have a good deal more financial and organisational slack than their competitive counterparts. Therefore discretionary spending on research and development may be more readily forthcoming. A counter argument to this is the X-inefficiency argument by Leibenstein (1966), where those earning supra-normal profits become less motivated to seek additional profits, through R & D for example. Competition may prod the firm to improve its technology in order to survive while the lack of it removes the threat and therefore the inventive incentive.

A third argument associated with market power and the incentive to invent is the appropriability argument. While rivals may have stimulating effects on technical progress in one respect, they may act as a disincentive to invention if they are able to reap the rewards the inventor deems as rightfully his through imitation. It is argued by Kamien and Schwartz (1972) that a strong market /

market position and the absence of significant competitors enhance the firm's ability to internalise the benefits of its own inventions. Appropriability may also be increased if the firm is able to extend the monopoly power from its existing products to new products due to command over distribution channels or by way of an established name in a particular industry.

The contradiction above points to the importance of recognising the multidimensional nature of a market environment in assessing its effects on the inventing firm. Not only is the number and relative size of competitors in a market important, but also their conduct in terms of rivalrous R & D behaviour. Kamien and Schwartz (1970) reconcile the contradiction by suggesting that competition encourages the diffusion of technical advances through imitation, while the lack of it is encouraging to major innovations. The effect of rivalrous behaviour on the incentive to invent is considered in more detail shortly, expecially with reference to product invention.

A fourth advantage of monopoly power as it relates to R & D activity may be the ability to hire the most talented researchers. Assuming that an imperfect market for R & D personnel exists, the firm with supra-normal profits will be able to outbid its less powerful and likely smaller counterparts. However as previously noted, talented researchers desiring a degree of work independence /

independence may find R & D activity in the large powerful corporation too bureaucratised, preferring either their own ventures or smaller enterprises.

While a number of the possible negative effects of market power on inventive activity have been mentioned, it is worth discussing a few additional drawbacks. Baldwin and Childs (1969) develop a model which shows market power diminishing the amount of original R & D undertaken in the firm in favour of imitative effort instead. While the smaller less powerful firm must innovate to improve its unfavourable market position, the firm with considerable market power finds itself in a position to gain from quick imitation. This strategy is termed 'the fast second.' Here firms with established reputations, access to better raw materials and components, established distributional channels and perhaps possessing scale economies, are able to outdo the innovator by imitation.

Schumpeter (1939) himself recognised the negative effect of too much market power prevailing throughout the economy, especially if it was in the hands of the older and more conservative firms. Schumpeter saw innovation arising from the newer evolving giants. A further point with reference to newcomers is made by Kamien and Schwartz (1980) who explain that the incentive to invent is always greater for the newcomer than the existing monopolist, all other things equal. This is because /

because the monopolist currently earning supra-normal profits must calculate the difference between profits after an invention and his current profits to arrive at his net gain from an invention. The newcomer however includes total profits from an invention in his calculation of net gain.

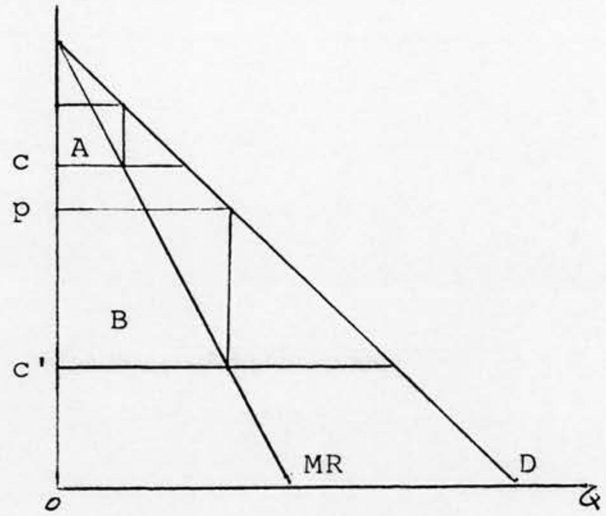
Kamien and Schwartz base the point above on the work of Arrow (1971) who was interested in discovering whether the incentive to invent was greater under perfect competition or monopoly. Arrow's analysis is interesting because on first glance it appears to contradict the Schumpeterian hypothesis; however a closer look shows that this is not the case. Arrow proved that the incentive to invent a cost-reducing invention is greater under perfect competition than monopoly. The reference however is to the industry using the cost-reducing invention rather than the industry producing it, with which the Schumpeterian hypothesis is concerned. The analysis by Arrow and the discussion that followed highlights some of the properties of process invention and their relationship to market structure. We therefore take up the analysis in more detail.

Cost-Reducing Inventions and Market Structure An article by Arrow (1971), already considered in chapter three, initiated considerable discussion concerning the market structure /

structure providing the most incentive for cost-reducing invention. The results of Arrow's analysis may be seen graphically in Figure 4.1 below.

Figure 4.1

Arrow's Model of Cost-Reducing Invention



Assuming constant marginal and unit costs of production (c), the effect of a cost-reducing invention is to reduce marginal costs of production from oc to oc'. This level of cost-reduction was labeled 'drastic' by Arrow because it results in a post-invention monopoly price, p, below the pre-invention competitive price, c.[1]

Arrow /

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1. Arrow also considered minor cost reductions where the post-invention monopoly price is above the pre-invention competitive price. Although the analysis is slightly more complex, the results are the same.

Arrow first considers an inventing firm within a competitive industry, which patents a cost-reducing invention and then licenses it for all other firms in the industry. Here the optimum policy for the inventor is to charge a per unit royalty on the use of the invention of (p - c'), so that the resulting output level is that which would be chosen by a monopoly. Profits to the inventor are clearly B. A monopoly, facing the same demand and cost curves, produces an invention and uses it itself. The net revenue gain to the monopolist is B - A. The monopolist's gain is less than in the perfectly competitive case because of pre-invention monopoly profits. Arrow's conclusion is that the incentive to invent is greater under competitive conditions than monopolistic conditions. It should again be stressed that the market structure reference is to the industry using the invention.

The Arrow model led to a number of criticisms and counter-criticisms from other economists. Demsetz (1969) criticised the analysis on the basis that the monopoly and competitive industry faced the same demand curve. This led to a lower pre-invention monopoly output than in the competitive case. When he worked through the analysis assuming that the two industries had the same pre-inventive output[1], Demsetz reached conclusions opposite/

1 Demsetz's proof awsumes that the monopoly's marginal revenue curve is the competitive industry's demand curve, making pre-invention competitive and monopolistic output the same.

opposite to those of Arrow or that the incentive to invent was greater with monopoly. In Demsetz's analysis the monopoly has the greater post-inventive output.

Demsetz's analysis, however, has been subject to a number of counter-criticisms. As Kamien and Schwartz(1982) note, a competitively organised industry does produce more output than a monopolistically organised one, under the same demand conditions. They argue that to ignore this fact is to ignore the objections to monopoly itself.

In a further discussion of Arrow's work, Yamey (1970) considers that a monopoly inventor and a monopoly user of an invention may not be one and the same. In this case, it is likely that the rewards from invention would be shared, thus diminishing the incentive to invent. This points to the problem of appropriability of an invention, which has been discussed in chapter 3.

Kamien and Schwartz (1982) view Arrow's analysis as a proof of the 'demand-pull' theory of Schmookler. This is because it points directly to the positive effect of market size on the incentive to invent. From the above discussion, it is clear that the total reward from a cost-reducing invention increases with the size of the market. The explanation lies in the indivisible nature of a cost-reducing invention once produced. The increase/

increase in productivity can be spread over additional units of output at no extra cost. Insofar as competitive output is greater than monopoly output, the inventor's total reward also increases with the competitiveness of the industry to which he is licensing it.

A further extension of the Arrow analysis by Kamien and Schwartz (1970, 1982) shows that the total reward for an invention, which reduces costs substantially, increases with the elasticity of the industry's demand curve regardless of its market structure. This follows directly from the previous discussion. The industry with the greater elasticity of demand experiences a greater increase in output given the cost reduction and output has a positive effect on inventive activity.

While the analysis by Arrow and his followers leads to important insights, it is simplistic in the sense that it assumes no rival R&D efforts. The 'no rivalry' assumption may not be too unrealistic for process inventions since they are internal to the firm if the firm is both the inventor and user of the invention. But, rivalry in R&D becomes very important in analysing the firm's incentive to produce product inventions. It is interesting to note, however, that Barzel's (1968) paper on competition between potential inventors of process innovations stimulated considerable work (particulary by Kamien and Schwartz, 1982) on rivalry. Barzel recognised that intense rivalry could result in a premature introduction of innovations compared to the 'social optimum'. His model, however, did not specify how firms took the presence/

presence of rivals into account. We take this subject up in the next section.

4.5 Rivalry and the Incentive to Produce New Product Technology

It is widely recognised that firms, especially in oligopolistic situations, often compete on the basis of product quality rather than price. As noted previously, the large majority of private industrial R&D expenditure is devoted to new product development and improvements rather than cost-reductions. Unlike inventions which reduce cost and whose benefits might be viewed as largely internal, the benefits of an improved product technology come from the market. Profit maximising firms therefore weigh the benefits of product technology changes in terms of market response against the costs of product invention and innovation. The market response might be a whole new demand function for a new product or a larger market share of a given demand for a product quality improvement. The costs of new product inventions may be significantly affected by the technological opportunities available in the industry. All other things equal, we would expect greater product invention by firms in 'high opportunity' industries.

Scherer's Model of Technological Product Rivalry

Scherer (1967), who recognised that new products and product improvements were susceptible to imitation, was

was/

was one of the first to develop a model of technological product rivalry[1]. He proposed that the increase in net revenues from the successful completion of an R&D project would depend on the date of completion, the quality of the end product (its ability to satisfy existing or latent demands) and the reactions of rival firms. A typical rival reaction to a product innovation might be increased R&D expenditure in order to bring the introduction of an imitation further forward in time. The costs of the R&D project in Scherer's model depend upon the state of technology, the quality of the end product (costs varying directly with the quality of an invention) and the speed of development. Scherer was particularly interested in the time pattern of R&D expenditure and its effect on the total cost of the R&D project. His significant contribution was the specification of a time-cost trade off function, whereby the compression of R&D project time by higher per period expenditures increases the total R&D project cost[2]. Therefore while there might be significant benefits from the early introduction of a new product, particularly if the payoffs for being first are high, there are also increased costs.

Scherer/

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1 An earlier model by Horowitz (1963) analysed 'The Research Inclinations of a Cournot Oligopolist' in the context of game theory. His results are essentially the same as Scherer's but his model is not as extensive.

2 Scherer's rationale for the cost increases are due to (1) mistakes from overlapping sequential research steps; (2) running alternative technical approaches concurrently to increase the probability of an earlier completion; and (3) conventional diminishing returns from allocating more technical personnel to a particular task. Mansfield et al., (1971) provide evidence supporting Scherer's time-cost trade-off function.

Scherer further specified a number of conditions of oligopolistic rivalry which lead directly to his results. One was that imitators engaged in product quality-matching as a reaction to innovators rather than quality leap-frogging. Another important specification was that of the benefits to an early completion. The benefits for being an innovative leader in a market-sharing game were due to: (1) the temporary slice of rivals' markets which could be gained before they were able to quality match and win markets back; and (2) the gain due to the permanent erosion of rivals' markets due to their being laggards. The latter factor or permanent erosion factor means a particularly big payoff for being first and invites strong aggressive reactions to accelerated R&D spending by rivals.

Scherer notes that, as in all cases of oligopolistic rivalry, no unambiguous profit maximising solution to R&D spending exists. However, he examines the Cournot solution, first for the duopolist and then extending the model to 'n' firms to reach important conclusions[1]. One significant result was that firms with smaller market shares are more likely to initiate a rapid pace of innovation than dominant firms, though the latter were likely to retaliate quickly as imitators. Although rigorous results were provided, Scherer also offers an intuitive interpretation (Scherer, 1967, p. 383):

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[1] The Cournot assumption in Scherer's model is that each firm takes its rivals R&D project time as a parameter.

> In a market-sharing game, the relatively small firm has much to gain by cutting into its bigger rival's market position through innovation, but less to lose when it trails its rival. A dominant firm has little to gain by innovating, but much to lose when its position is attacked by a smaller innovator.

While the citation above applies to a given market, Scherer's conclusions are the same for an innovation leading to a new market. The larger the target market share of its imitating rival, the more rapidly a smaller firm would conduct its product development.

Scherer's results contain a number of qualifications, two worth mentioning here. One was that the ability of the smaller innovator to penetrate a market might be limited by internal growth constraints, thus decreasing the potential benefits and incentives to conduct R&D. Another important qualification is related to the number of firms in the market. While stimulating rivalry, an increase in the number of firms beyond some point might lead to market overcrowding and reduced profits for all. Scherer (1980 , p. 429) later elaborated on this point when he described the 'clash of structural propensities' as follows:

> In terms of the marginal conditions for profit maximisation, an increase in the number of sellers is conducive to more rapid innovation. This influence can be called the stimulus factor. But in terms of the requirement that expected profits from innovation be non-negative, an increase in the number of firms can, beyond some point, discourage rapid innovation. This influence might appropriately be called the market room factor.

The/

The clash of structural characteristics described above makes it difficult to predict the effect of market structure on the incentive to invent. Whether rivalry or appropriability of benefits dominates must be left to empirical analysis.

Before leaving the early Scherer model, a few of the welfare implications might be noted. First, from the firm's point of view, rivalry provides a stimulus to over-invest in inventive activity. In the Scherer case firms end up in the classic prisoner's dilemma situation where the dominant strategy results in bringing forward R&D results in time[1]. Through mutual trust firms could delay product introductions to extend R&D projects, lowering costs. Scherer, however, provides some rationale for un-cooperative behaviour with respect to R&D decisions. One factor leading to mutual distrust is that information concerning rival R&D strategies is even more imperfect than that concerning price strategies. Also, quite different from price decisions, R&D project decisions are in a sense 'one of a kind' in that all projects differ somewhat. Furthermore, firms tend to overestimate their own ability and underestimate their rival's ability to succeed in the game of knowledge production.

As far as the welfare implications for society when a completely new product is introduced, Scherer refers to Usher's (1964) proof showing that any commercially/

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[1] In the pure market-sharing model firms would maximise their joint profits from restraining from R&D altogether. This is because the gains of leaders and losses of followers cancel each other out while the costs of R&D persist.

commercially profitable product invention confers a net benefit on the community as a whole. Usher however warns that when the profits from inventing first are high, there may be wasteful duplication of research efforts among competing inventors.

For Scherer's market-sharing rivalry situation, Usher's work demonstrates that innovations which are privately unprofitable may confer social net benefits, depending on the shape of the community indifference curve between the product of the invention and the products previously available. Barzel (1968) reached a similar conclusion for process inventions.

Scherer's model which is a 'game theory' approach to technological rivalry has been extended by a number of economists including Loury (1979) and Dasgupta and Stiglitz (1980). The difference between Scherer's model and the later models rests on the specification of the development cost function. In the Scherer model it was deterministic, while in the later models it is stochastic. Here the probability of completing an R & D project increases with both time and the level of R & D expenditure. Kamien and Schwartz have taken a different approach to the rivalry problem, viewing it from the angle of individual firm behaviour. Since this is the approach that we take in this thesis, we now turn to their work.

The Contributions of Kamien and Schwartz Kamien and Schwartz have made a significant contribution to the theoretical /

theoretical literature concerning the effects of rivalry and market structure on innovative activity. Much of their work, summarised in a recent book (Kamien and Schwartz, 1982) was inspired by the dilemma, noted by Scherer; that is the dual effect of structural characteristics on the incentive to invent. Kamien and Schwartz (1982, p.118) explain the dilemma by way of the 'carrot and stick' parallel. The carrot of innovational profits stimulates invention for offensive reasons. The ability of the firm to appropriate the rewards through a strong market position, with few rivals, is beneficial. However, rivals also stimulate invention for defensive reasons with the threat of loss from rival innovation acting as a 'stick'.

In their 1982 model of product innovation, Kamien and Schwartz consider the individual firm both as a potential innovator and potential imitator, depending on whether T, the firm's date of product introduction is earlier or later than v, the date of its rival's product introduction. The net receipts received by the firm from the beginning of the new product's development period are summarised by Kamien and Schwartz (1982, p.113) as follows:

r_o		p_o		P_1	
flow	T	flow	v	stock	t

if the firm is an innovator and

r_o		r_1		P_2	
flow	v	flow	T	stock	t

if /

if the firm imitates, with all receipts calculated to their present value and where:

- r_o is the firm's receipts on its current good
- r_1 is the imitator's receipts on its current good after an innovation which is a substitute, where $r_1 < r_o$
- p_o is the innovator's receipts before imitation
- P_1 is the innovator's entire profit stream after imitation
- P_2 is the imitator's entire profits stream after it has imitated

The profit maximisation problem for the firm, in the situation above, becomes one of choosing the optimal T or R & D project development time which maximises the difference between expected receipts and costs. Kamien and Schwartz assume here that total development costs are subject to the time-cost tradeoff function developed by Scherer, with higher costs being the result of compression of development time. Their expected benefit function is somewhat different however, in that they realistically assume that a firm's decision as to its rate of innovation depends not on its rival's actions, but on its own assessment of its rival's intentions. The uncertainty surrounding rival product introduction dates is specified by a subjective probability function. Expected profit streams from innovation therefore become dependent not only on net profit flows, but also on the probability that they will occur, or the probability of a rival's preemption.

A significant theoretical contribution of Kamien and Schwartz, is their attempt to specify more accurately in their profit-maximising model 'rival intensity'. They

(Kamien /

(Kamien and Schwartz, 1982, p.114) do this by defining 'hazard rate' which is the probability that a rival will introduce its product innovation in the next moment, given that the rival has not done so already.[1] An increase in rivalry is realised in an increase in the hazard rate which depends on a hazard parameter and a non-decreasing function of time. Of particular interest to Kamien and Schwartz is the change in the optimal time of innovation with a change in the hazard rate or the intensity of rivalry.

An important result of the maximisation problem described above is that the speed of introduction of innovations with a large payoff will increase with an increase in the intensity of rivalry up to a point and then will slow down as rivalry increases further. An intuitive explanation put forth by Kamien and Schwartz (1982, p.142) is as follows:

> Initially, the fear of losing the race spurs additional expenditure on development but as the intensity of competition continues to grow, the firm begins to fear that it will not get the reward from being the first and will also lose the development costs. It then reduces investment in development and thereby postpones the planned introduction date.

A second result relates to innovations with a more modest payoff. Here as the degree of rivalry increases development of the innovation is delayed. In this situation, no rivalry yields the maximum rate of inventive activity /

1. The composite rival referred to in the analysis may appear from a number of sources: from current rivals, firms in other markets or entirely new entrants.

inventive activity.

Another finding of Kamien and Schwartz, which was noted earlier by Arrow (1971), is that the presence of extraordinary profits on current products reduces the firm's inventive activity. This is because the firm realises only the difference between current profits and profits from innovation as its reward. Thus newcomers should have faster rates of invention than established firms all other things equal. Also, this explains why established firms often have a greater incentive to innovate in industries and sectors other than their own.

Kamien and Schwartz complicate their model of innovation under rivalry by considering a number of extensions which make it more realistic. For example they consider the effects of imposing the self-financing of R & D on firms undertaking innovation. They find that self-financing is not a limiting factor to a firm, except where expected profits from the innovation are many times larger than current profits. In the case of large expected payoffs, the firm would like to step up its development pace, but is constrained by the current level of profits or its liquidity.

While models of rivalry following the Scherer and Kamien and Schwartz lines are currently most prevalent, they /

they leave out a number of factors which have been hypothesised to influence inventive activity. While not as extensively developed as the rivalry hypothesis, they deserve some mention here.

4.6 The Diversification Hypothesis

The firm's degree of diversification has also been identified as a variable having some influence on its incentive to invent. The argument is that the firm with a diverse product line will be better able to use the sometimes unanticipated results of its research efforts. The expected profitability of R & D is thus higher for diversified firms and they tend to undertake more of it. Diversified firms may also have lower R & D risks than their narrower-ranged counterparts due to the variety of independent R & D projects going on simultaneously.

It is important to emphasise that Nelson's (1959) original diversification hypothesis referred to the conduct of basic scientific research by the firm. Nelson (1959, p.303) stated:

> Strangely enough, economists have tended to see little economic justification for giant firms not built on economies of scale. Yet it is the many-product giants, not the single-product giants which have been most technologically dynamic, and to the extent that we wish the private sector of the economy to support basic research, we must look to these firms.

Nelson further explained that applied research was likely to be profitable in firm's with a narrow technological /

technological base, because it could be directed toward the solution of the firm's specific problems and could be easily translated into patentable products and processes. On the other hand, due to the greater uncertainty involved, product diversification with a wide technological base was a prerequisite for basic research. Diversified firms would be better able to profit from whatever discoveries might result.

While the diversification hypothesis applies more directly to basic research, it has been extended by a number of economists, including Comanor (1965) and Grabowski (1968) to relate to the conduct of all R & D by private firms.

4.7 An Alternative Approach to Process Invention

Concerning the subject of process inventions, it is worth mentioning another approach which is much different from the Schumpeterian line of analysis. Most studies of inventive activity emphasise the size or market power of the inventing firm, however here the emphasis is on the optimal mix of the firm's factor inputs, R & D being one factor input.

The approach stems from the work of Hicks (1932) which was concerned with the bias of invention. Hicks hypothesised that a change in relative factor prices would stimulate the search for new methods of production which would use more of the now relatively cheaper factor and less of the expensive one, which was expected to be labour. While Hicks' hypothesis created a considerable amount of /

of discussion concerning the labour vs. capital-saving bias of inventive activity, we will not be concerned with that here. What is of some interest is an extention of the theory which relates to the rate at which private firms are producing technological changes.

Schott (1976) suggests that R & D expenditures are influenced by changes in relative costs and prices. Her argument is that the more relative factor prices change the wider the choice of techniques industry would like. As an example she proposes that recent increases in oil prices ought to have induced more research in an attempt to widen the choice of energy alternatives. In a more rigorous model of induced factor-augmenting technological change, Kamien and Schwartz (1969) show that the rate of advance varies directly with factor costs.

In a further more extensive investigation of the demand for R & D as a factor input, Schott (1978) hypothesizes that changes in R & D spending are intimately connected with other factor decisions. Her investigation considers the complementarity and substitutability of R & D with other factors of production both in the short-run and long-run.

4.8 The Product Cycle Approach to Technological Change

Another view of technological change in an industry is closely associated with the theory of the product cycle which has been important to international trade studies (for example, see Vernon, 1966). The theory is reviewed here /

here because it emphasises the differences between process and product changes. The general prediction is that the stage of development an industry has reached determines its propensity to gain from particular types of technological changes.

The evolution of a product from birth to maturity is often described in three stages. In the first stage of a product's development, most technological applications are to the product's characteristics. A new product may at first have no close substitutes and be relatively price inelastic. The product in this stage is unstandardised and frequent changes are necessary to iron out product difficulties and to redefine characteristics. If technological possibilities are significant competitors may respond with imitations and technological rivalry may develop. Production processes tend to be labour intensive in the first stage and any capital equipment tends to be general purpose.

In the second stage of development price competition becomes more important. The product technology becomes stabilised and the production system designed for increased efficiency becomes more capital intensive. In this stage the production process as a whole remains relatively segmented and improvements are made to various subprocesses. Although product competition may persist, it will tend toward differentiation which does not impair volume production. Parker (1974) adds that for some products with significant potential this stage may be delayed /

delayed, but eventually a point is reached where minor improvements become the basis of any product competition.

In the final development stage the product is fully mature and there are few improvements either process or product coming forward. The production process becomes so well integrated that changes become very costly. Price competition becomes paramount and capital intensive mass production methods are necessary for survival. Abernathy and Townsend (1975) explain that process redesign may be initiated at this stage by the development of an entirely new technology or shifts in the market environment. If the mature industry resists these pressures then technological change becomes revolutionary rather than evolutionary.

Abernathy (1978) in a later paper on the product cycle in the U.S. automobile industry, addresses the dilemma which becomes apparent in the evolutionary process. While movement toward the final stages offers the benefits of high productivity, this is only at the cost of inflexibility and decline of innovative potential. The mature industry therefore can find itself vulnerable to stagnation. A possible option for a firm or industry is to remain in the particular stage offering the best tradeoff of conflicting objectives. This may mean reversing or halting the evolutionary process. Abernathy found that the development of the highly automated engine plant lessened its ability to adapt to needed changes in air-pollution control and fuel economy. On the other hand the /

the auto-assembly plant remained more adaptable with resulting lower efficiency in production.

The analysis above is also the general theme of Utterback (1979) who argues that the conditions for rapid innovation in an industry are much different from those required for high levels of output and efficiency in production. His prediction is that a strong commitment to R & D is characteristic of the middle stages of the product cycle, with emphasis on both process innovation and product differentiation through functional improvements.

A related hypothesis is put forth by Wilson (1977) who views product innovation as a trade-off against process innovation. He argues that the more the physical characteristics of a product are expected to change, the lower the effort devoted to process changes. This is both because rapid product obsolescence constrains any potential for cost reduction and because of limited resources for R & D. Wilson sees the technological environment and degree of product rivalry as having substantial influence on the firm's choices. These characteristics however may be more predominant at a certain phase of the firm's product cycle. The trade-off hypothesis may be criticised for being a bit too 'black and white'. New products and even product improvements may necessitate changes in the production process, while process changes may enable further changes in products.

4.9 Summary

A review of the theoretical literature shows that a good deal of effort has been devoted by economists in the past two decades to technological change at the microeconomic level. Much of the recent theoretical work is highly rigorous, especially that concerning market structure and rivalry. However, while models of technological rivalry have been developed extensively in theory, the problem of identifying a variable to represent the 'intensity of rivalry' empirically remains. The problem of measurement also becomes important in testing the 'technological push' hypothesis. Chapter five, which follows, discusses efforts to test the theories of invention and innovation which have been outlined here.

CHAPTER FIVE

A REVIEW OF PREVIOUS EMPIRICAL WORK

Since the mid-1960's, there has been a substantial amount of empirical work related to testing theories of inventive and innovative activity. This chapter reviews and summarises such work, using the same system of subheadings as that used for describing theoretical studies in Chapter four. Because the scheme focuses on particular variables, such as 'technological opportunity', rather than individual studies or authors, and because most studies use a multivariate approach, some overlap in the discussion is unavoidable.

The majority of empirical studies completed in the field of invention and innovation have used U.S. industrial and firm level data. There have been however, a number of U.K. studies which will be of special interest here. Rather than a thorough description of each paper, the chapter seeks to focus on those of greatest interest to this thesis, which are: those using patent data to measure technological change; those using U.K. data and; more recent studies shedding new light on the behaviour of variables. In addition to summarising both the approach and results of the various papers with respect to variables tested, some attention is also given to the problems inherent in empirically testing theories of this nature.

A number of surveys of the empirical literature have been /

been of help in compiling this review, particularly the recent survey by Kamien and Schwartz (1982). Two other surveys should also be mentioned in this respect: an earlier review by Kamien and Schwartz (1975); and that of Kennedy and Thirwall (1972).

5.1 The Demand-Pull Hypothesis

Original Work by Schmookler Jacob Schmookler (1966), who is generally credited with the 'demand-pull' theory of inventive activity, also tested his theory, making extensive use of U.S. patent data. While others, both in the U.S. and the U.K. have both supplemented and challenged his work, Schmookler's original test remains distinctly important.

Schmookler's empirical model, like its theoretical counterpart, emphasises capital goods inventions. As explained in Chapter four, in Schmookler's view, demand or the extent of the invention using industry's market, was an important factor in stimulating capital goods inventions associated with the industry. Schmookler carried this approach through in his empirical model, hypothesising that capital goods inventions would be distributed among industries of use in relation to the amount of investment in the user industries.

In cross-sectional tests of his hypothesis on twenty-three U.S. industries, Schmookler examined the relationship between patent applications on capital goods inventions to be used in industry and industrial investment, both /

both variables in logarithmic form.[1] Patent applications were counted over three years, beginning one year after that in which industrial investment was measured. Schmookler's results show a proportionate relationship between the distribution of capital goods inventions among industries and the distribution of industrial investment.[2] Furthermore the lagged structure of the regression equation implied that 'a 1 per cent increase in investment tends to induce a 1 per cent increase in capital goods invention' (Schmookler, 1966, p.144). The regressions, in addition, provided a very good fit, with the variation in investment explaining about ninety per cent of the variation in patenting. When Schmookler tested the argument that industrial size, as measured by number of workers, was responsible for the movement in both variables, he found an insignificant role for size.

Schmookler's work involved considerable effort in terms of classification of patented capital goods inventions /

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1. Schmookler's time-series analysis of the U.S. railroad, building and petroleum refining industries provide him with essentially the same results as his cross-sectional tests.

2. For example, Schmookler's (1966, p.144) regression equation for 1948-1950 patenting, where P represents industry patents and I represents industrial investment is as follows:

$$\log P_{1948-50} = \underset{(0.116)}{0.598} + \underset{(0.070)}{0.940} \log I_{1947} \quad r^2 = 0.905.$$

The numbers in parentheses are the standard errors of the coefficients.

inventions to their industries of use. Like Boehm (1967) in his industrial classification of U.K. patent data, Schmookler attempted to link patent office subclasses to industries as defined in the Standard Industrial Classification (SIC) manual. Both faced the problem of a patent system classified by technological function, which was not easily converted to a classification system based on industrial principles. Schmookler used a criterion such that subclasses of the patent scheme, and therefore all patents under these subclasses, were assigned to an SIC industry, if at least two-thirds of the patents, based on sampling the subclass, pertained to a particular industry. This meant however, that some subclasses would be eliminated for use in his data base. Another problem leading to the exclusion of some capital goods inventions is that a number, for example those involving diesel engines, could not be assigned to a single using industry. Schmookler estimated that even if his database was incomplete, ninety-five per cent of the inventions used belong to the industries to which they are assigned.

While Schmookler's own work involved classification of inventions by industry of use, others in the field classified inventions by the industry supplying them. In order to determine whether this difference affected his conclusions, Schmookler ran further tests. Using Scherer's sample of patents of 448 large U.S. corporations, classified /

classified by industry of origin, he ran three regressions, taking alternatively values for industry sales, assets and employment in 1955 as the independent variable and patents granted in 1959 as the dependent variable. From the point of view of the supplying industry, sales, assets and employment were indicative of the extent of the market served by the industry. He found that the relationship between originating industry size and patenting was again log linear, however these regressions provided much lower r^2 values. Schmookler attributed the appreciably smaller proportion of variance explained when inventions were classified by the producing industry,to differences in technological opportunity among industries. While in Schmookler's view the richness of an industry's knowledge base had little effect on the inventions made to improve its production process, the differences in inventive potential of rival product technologies was important. Technological opportunity would therefore be a factor in determining which capital goods industries were tapped to improve a production process.

The Contribution of Scherer Scherer (1982) reconsiders Schmookler's approach to testing the demand-pull theory using a new data base.[1] Scherer's patent data, classified by a research team into both an industry of use and an industry of origin, are from a sample of 443 large U.S. corporations /

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1. Scherer (1982, p.227) notes two limitations of Schmookler's tests: (1) the sample of industries chosen for his investment-capital goods patent analysis was small and over-represented by 'older industries' such as papermaking and apparel; and (2) the sample of patents classified by industry of origin was different from the use-oriented sample.

corporations over a 10 month period of time in 1976-77.[2] Scherer includes material goods inventions in his data base along with capital goods inventions, introducing material input purchases as the demand-pull variable for the former.

The results of Scherer's test of the logarithmic relationship between user industry investment and capital goods patents classified to user industries is much stronger than his test of the comparable relationship for material input inventions. He concludes that Schmookler chose the best suited class of inventions for his analysis of the demand-pull theory. His tests however, result in r^2 values much lower than Schmookler's. Scherer also found the elasticities of invention with respect to investment and material input purchases respectively, to be significantly less than one -.69 for capital /

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2. Scherer's team was comprised of four students with specialties in the chemical and electrical engineering fields. The team found 34 per cent of firm patents too broad in terms of use to associate with any subset of using industries.

capital goods and .44 for material inputs.[1] Scherer (1982, p.232) comments that 'appreciable diminishing marginal returns appear to prevail'.

Scherer also regressed patents classified by industry of origin on originating industry sales in logarithmic form, finding a regression coefficient very much closer to unity (.904). He remarks (Scherer, 1982, p.232) that this implies 'equivocal' support for Schmookler, given that the flow of inventions appears in his own tests more closely correlated with originating industry sales than using industry investment.

Scherer also acknowledges the role of technological opportunity, adding dummy variables for technology class into his 'originating industry' regression equations. This significantly raises the explanatory power of his results. Scherer's work with the technological opportunity variable is described more fully in section 5.2.

Overall, Scherer (1982, p.236) concludes that while his results do 'some damage to Professor Schmookler's findings on the role of 'demand-pull', the theory survives at least for capital goods inventions. He adds that both /

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1. Scherer also ran tests on two subdivisions of capital goods, those processes for internal use by the originating firm and capital goods product inventions for sales across industry lines. His general conclusion was that external markets were at least as responsive in transmitting demand-pull stimuli as internal markets.

both demand and technological opportunity differences however, need to be accounted for in explaining technological change.

It is important to note that in both Scherer's user industry and industry of origin tests, patents lagged the demand-pull variables by two years in the best-performing results. With an average 9 month lag in invention to application and an average 19 month lag in application to issuance, this leaves no room for a lag between the emergence of demand influences and invention. Scherer attributes his results to chance or a tendency for corporate inventors to anticipate favourable demand conditions even before they fully materialise.

Going beyond Schmookler's model, Scherer also tests the strength of the invention-using industry's output growth as a demand-pull variable. By adding this variable, which turns out to be positive and significant, to his regression equations for user industry capital goods inventions and material input inventions, he is able to add significantly to their explanatory power. Scherer concludes (1982, p.235) that 'past increases in using industry output provide modest additional stimulus to invention above and beyond current levels of demand.'

<u>Other Tests of the Output Growth Variable</u> A number of other economists have tested the influence of sales or output growth as a demand-pull variable, but unlike the Scherer test above, these tests have been at the firm level /

level of analysis. Mueller (1967), for example, found a positive influence for the firm's ten year growth in sales on its R & D expenditure for 67 U.S. firms.[1] He attributed the positive influence to both a reduction in uncertainty due to higher growth and the pull of demand. He added that the sales growth could be the result of the firms past R & D expenditures and if this were true the variable would serve as a measure of the firm's expectations.

Elliott (1971) however in a slightly different type of cross-sectional test, obtained contrary results. Using data from 53 U.S. firms in 16 industries, he found that the five year average growth rate for all firms in the industry of the sample firm was not a significant influence on firm R & D expenditure. He concluded that there was a considerable degree of independence of firm R & D decisions from longer range industry growth patterns.

Rosenberg (1977) on the other hand, found a positive and significant effect for five year firm sales growth on the percentage of total employment allocated to profession R & D personnel in 100 U.S. firms.

Stoneman's U.K. Tests In the United Kingdom, Stoneman's (1979) work comes closest to that of Schmookler and /

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1. While Mueller (1967, p.65) obtained his predicted positive coefficients for sales growth, his t values were not very high.

and Scherer in the U.S. Stoneman tests Schmookler's demand-pull theory of invention using an inter-industry distribution of U.K. patents, 1931-1960, compiled by Boehm (1967). He adds however, to the Schmookler model, a variable representing technological opportunity differences between industries. This is represented in his empirical work by industry R & D expenditure per patent.

Stoneman (1979) developes a theoretical model of firm decision-making with respect to inventive output, which recognises both expected revenues and expected costs of the activity. Expected revenues from an invention are influenced in his model by: (1) the size of the potential market for an invention, represented by the output of the user industry; (2) the speed of diffusion of the invention, represented by the investment to output ratio of the user industry; and (3) the number of inventions being produced in a given industry - the greater the flow, the lower the expected return to any one invention.

When aggregating his model to the industry level to conduct his empirical tests however, Stoneman (1979) assumes that the industry producing and using the invention is one and the same. This is necessary due to the limitations of Boehm's database. Boehm (1967) classified inventions to the industry of application; product inventions are attributed to those making the products /

products and process inventions are attributed to industries using such products.[1] Therefore, while necessary, Stoneman's assumption renders the interpretation of the demand-led variables somewhat different to those of Schmookler. Stoneman notes that given the broad definition of industries used, the probability of using and invention-producing industry being the same is high.

Stoneman tests his model in logarithmic form on time-series data for thirteen U.K. industries and cross-sectional data for fourteen industries, making cross-sectional tests for a number of years, 1949-60. In cross-sectional tests, both diffusion speed (investment/output) and market size (output) are significant at the 10 per cent level in at least half of the years tested. This leads Stoneman (1979, p.400) to conclude that 'a preferred measure of the demand effect ought to consider both market size and diffusion speed'. The coefficients for market size however, are substantially below one (the highest being .731 in 1960) which implies a less than proportional relationship between this variable and inventive activity. Results here however are not strictly comparable with Schmookler's due to the forementioned differences in assumptions. Also Stoneman's tests /

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1. Boehm (1967) experienced the same difficulties as Schmookler in converting a technology based patent classification scheme to an industry based classification.

tests are made on all patents, not just those pertaining to capital goods inventions.

Stoneman's general conclusion is that not only demand, but also the costs of inventing play a role in influencing industrial inventive activity. With variables which represent both demand and technological opportunities he is able to explain a good deal of the variation (with r^2's from .661 to .848) in cross-sectional tests of industrial patenting. Technological opportunity is discussed in the next section to which we now turn.

5.2 The Technological-Push Hypothesis

A major difficulty to be faced in empirically testing the technological-push theory of inventive activity is the measurement of the independent variable. Because technological opportunity cannot be measured directly, economists have resorted to a number of alternative approaches. In some cases unexplained variation in inter-industry inventive or innovative activity is attributed to a missing variable, the differences in the science-base of the industries concerned. Another approach is the use of dummy variables to categorise firms or industries as being characterised by high or low technological opportunities. More recently other /

other quantifiable variables have been used as proxies for the somewhat abstract concept. Although none of the approaches are completely satisfactory, results of the empirical tests have shown that more work on testing the technological push theory is justifiable.

U.S. Studies Stressing Product Differentiation

Phillips (1966) in contrast to Schmookler (1966) who had emphasised the role of demand, was an early proponent of the 'technological-push' theory of innovative activity. Phillips undertook what he described as a 'crude' empirical test of the hypothesis that the strength of the association between the organised sciences and the technologies of specific industries explained interindustry differences in technological advance. In a two-step regression analysis to explain differences in R & D performance between estimated industry performance in eleven U.S. industries and the three size groups of firms within each industry, Phillips found the interaction between high concentration and low product changeability as firm size increased to swamp the simple size effects of firms.[1] In other words a high correlation between research activity in the industry /

1. Using National Science Foundation data on company financed R & D funds per hundred dollars of value added, 1958, for 3 size classes of firm in each of 11 industries, Phillips first tried to explain R & D differences between industries. He then attempted to explain differences in R & D performance between the estimated industry performance and the three size groups of firms within each industry.

industry as a whole and research activity for each firm size in the industry existed.

The important independent variable in Phillips' regression analysis was the industry's index of product changeability or differentiability. Each industry's index was obtained by studying the descriptions of the primary products of each four digit SIC industry within the eleven two digit SIC industries tested. Each product was assigned a code depending on a subjective evaluation of the extent to which current science permits functional product differentiation. The figure for each industry was an average number for the products of the group.

Comanor (1967) followed Phillips in emphasising the ease of product differentiation as important in R & D decisions. Using data from a large number of U.S. firms classified into thirty-three industries, he conducted an inter-industry analysis of the influence of a number of factors on the level of industrial R & D personnel. His analysis showed R & D levels, adjusted for firm size to be far greater in industries producing consumer durable and investment goods than in those producing consumer non-durables and material inputs.[1] He concluded that in industries where the development of new products was a major /

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1. Comanor (1967) determined this by testing for differences in intercepts when variables representing industry concentration were regressed on research personnel for each of the two groups. The intercept for consumer durables and investment goods was significantly higher than that for consumer non-durables and material inputs.

major source of rivalry, such as in consumer durables and investment goods, competitiveness in research would be an important element in market behaviour. While stressing product differentiation through R & D, there is some question as to whether Comanor linked technological opportunity directly to the ease of product differentiation as reported by Kamien and Schwartz (1982). Comanor (1967) in his own article states that his analysis of inter-industry R & D levels does not consider technological opportunity.

Wilson (1977) followed the Phillips and Comanor approach with regard to product differentiability in his study of the R & D effort and the licensing of inventions among 350 U.S. firms. He identified however, two dimensions to each firm's technological environment: (1) the richness of opportunity for product change arising from exogenous advances in science and technology and; (2) the ease with which the physical characteristics of products can be changed. Both, he argued, would have a positive influence on the firm's decision to undertake research.

Assuming that a firm's technological environment can be represented by the industry in which the firm operates, Wilson (1977) used data on industry basic research expenditures to classify firms into high, medium and low opportunity industries. The share of a durable goods industry's output sold to the consumer, investment and government sectors combined (calculated from input-output tables) /

tables) measured the ease of product differentiation. Wilson's regression results show both technical dimensions to significantly influence firm research intensity (R & D expenditure/sales).

In another U.S. study, Shrieves (1978) accounts for both product market and technological characteristics in testing the relationship between innovative activity and market concentration on 411 U.S. firms. Shrieves took his sample of firms from those which were included in the publication Industrial Research Laboratories of the United States. This enabled him to use data on employment of scientists by various disciplines to classify firms according to their technological characteristics on an objective basis. A firm's product market characteristics are determined by the three digit SIC industrial code to which it is assigned and in turn by that industry's sales of consumption goods, investment goods and materials as determined by input-output tables.

The Shrieves' study makes use of factor analysis to reduce the dimensionality of the product-market characteristics to two and technological characteristics to five. Four of the five technology factors describe the relative involvement in firms, through employment of scientists in four broad areas; (1) life sciences,(2) electronics and aerospace, (3) mechanical and electromechanical and (4) chemicals. The final technology factor is dominated by a capital intensity variable which suggests this to be an index of the degree of process orientation or the 'flow characteristic' /

characeristic' of a production technology employed by an industry. The two product market factors are (1) the relative involvement in production of material inputs and (2) the relative involvement in production of durable equipment.

Shrieves found, in his multiple regression analysis, the degree of involvement in the life sciences to be a significant determinant of innovative effort. The factor representing mechanical and electromechanical technology was significantly inversely related to research effort, while the other technological factors exhibited weak inverse relationships. Shrieves concludes from these results that areas relating to the life sciences are relatively 'fertile' in terms of technological opportunities. The results however do not show as one might expect a significant positive relationship between the electronics and chemicals factors and innovative activity.

Both product market characteristics (involvement in material inputs production and involvement in durable goods production) had positive and significant regression coefficients in Schrieves' results. From this he concludes that industries scoring low in both factors, or those primarily engaged in consumer goods can be expected to allocate little of their resources to R & D rivalry. Again Schrieves' findings are somewhat surprising for the factor representing material inputs, since such goods tend to be low in terms of product differentiability.

<u>Other</u> /

<u>Other U.S. Studies</u> A number of other U.S. studies have used various methods to account for the technological opportunity variable in empirical tests of inventive activity. Although these methods differ, almost all of the studies have found the variable to have a significant and positive influence.

Mueller (1967), for example, tests a simultaneous firm decision-making model which includes four dependent variables: capital investment, R & D expenditure, advertising expenditure and dividend payments. Using data from 67 U.S. firms for four years, 1957-60, his results showed the independent variable to have the most explanatory power, as far as firm R & D expenditure was concerned, to be an industry index of R & D expenditure. Mueller concluded that the industry R & D index represented inter-industry technology differences.

Bailey (1972), in his analysis of U.S. pharmaceuticals, reached a different conclusion from that of Schmookler as far as the exhaustion of technical opportunities is concerned.[1] He found new drug introductions per dollar of R & D spending to be negatively related to the depletion of research opportunities. As an index of depletion he used a seven-year moving average of past total new drug introductions. /

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1. The conclusions of Bailey (1972) and Schmookler (1966) are not strictly comparable since the former was considering the depletion of product technology opportunities while the latter was concerned with production technology. According to Schmookler a variety of product technologies in capital goods industries might be able to meet the need of a changing production technology.

introductions. Grabowski, Vernon and Thomas (1978) testing Bailey's regression equation using several years of additional data, found the depletion coefficient to be negative but insignificant. They don't as a result of their test however, dismiss the possibility of depletion of opportunities as an explanatory factor for the decline in new product introduction in drugs since the 1960's.

Scherer (1982), in his recent retest of Schmookler's demand-pull hypothesis, also introduces technological opportunity into the analysis. He classifies 245 U.S. industries into seven categories according to 'the perceived richness of their knowledge base'.[1] Dummy variables representing the technology classes are then entered into equations regressing patents produced in an industry on industry sales or the demand-pull variable. Scherer finds that the addition of the technological opportunity dummies raise the explanatory power of his simple demand-pull regressions significantly. He (Scherer, 1982, p.236) concludes that 'clearly differences in opportunity play a large and easily systematized role.'

Scherer /

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1. Scherer's seven categories are as follows: organic chemicals, other chemicals, electronic systems and devices, other electrical equipment, the metallurgical trades, industries with 'traditional' technologies, such as sugar refining, textile weaving and cement making, and a base case consisting most of industries with mechanical technologies.

Scherer (1965a) in an earlier study had used a slightly different technique in identifying the inter-industry differences in technological opportunities. Using data from 352 of the largest U.S. corporations, he first conducted a simple regression of firm patenting activity, 1959 on firm sales, 1955. He then placed the firms in one of 14 industries and again conducted the regression for each industry. By letting each industry assume its own slope and intercept, he was able to explain all but 16 per cent of the total variance in corporate patenting about a grand mean. This was a gain of 42.5 percentage points over his first simple regression. Scherer attributed 30 out of the 42.5 percentage point increase in explanatory power to technological opportunity differences among industries. The remainder he attributes to differences in the propensity to patent among industries.[1]

Studies Using U.K. Data

While most empirical studies which have included the technological opportunity variable have resorted to dummy variables to represent industry differences, Stoneman (1979) in his U.K. test of Schmookler's demand-pull theory develops another quantifiable measurement. He represents the differences in industry opportunities by R & D expenditures per /

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1. Scherer calculated the 12 percentage point gain due to differences in the propensity to patent by first regressing patent output on R & D employment for 352 firms and then introducing individual industry slopes as dummy variables. The r^2 for the regression including the industry slopes is 12 percentage points higher than the simple regression.

per patent produced in an industry. Interpreting the variable as representing the supply side of the inventing industry, Stoneman argues that an industry with extensive technological opportunities would be reflected in lower costs per patent than one with limited opportunities. He hypothesises that the inventing output of an industry will be influenced by both cost and demand parameters.

Stoneman's use of a quantifiable proxy for technological opportunity is an important step forward from the assessment of technological opportunity through subjective judgement. His use of the R & D per patent measure however does lead to some questions. As noted in section 5.1, Stoneman tests both demand-pull and technological -push variables as determinants of U.K. industrial patenting activity in both time-series and cross-sectional tests. This however, as Stoneman notes himself, leads to the simultaneity problem of having the number of patents both as the dependent variable and as the denominator of the independent technological opportunity variable.[1]

Stoneman however finds in both cross-sectional tests for 14 U.K. industries and time series tests for 13 of these industries that not only demand but costs have an important role to play in determining inventive activity. His cost term is significant at the 5 per cent level in each /

1. Stoneman (1979) defends his empirical equation however by pointing out that while the dependent variable takes values over a number of years, the independent cost variable is calculated for only one year and is used to represent technological opportunity in all years. Therefore the two values are the same only for one year.

each year 1949-60 in his cross-sectional tests.

Another recent U.K. study using quantifiable variables to represent technological opportunity is that by Waterson and Lopez (1983). Their study is particularly relevant since they find technological opportunity to be the main discernible influence on U.K. industrial research intensity as measured by R & D expenditure as a percentage of sales. In contrast average industry firm size and the level of concentration have virtually no influence on industry research intensity.

Waterson and Lopez include two variables as proxies for technological opportunity, a variable representing capital intensity and a variable representing the rate of technical progress as measured by growth in output per head over a seven year period. They argue that research is likely to be more productive and can be adapted more quickly in industries which invest relatively heavily. The technical progress variable, according to Waterson and Lopez, captures a rather different aspect of technological opportunity as it is not correlated with capital intensity.

Despite significant results for both technological opportunity variables, the measures used must be questioned on theoretical grounds. A basic criticism is that the two measures are poor proxies for the theoretical concept of the underlying scientific knowledge base associated with an industry. The basis used by Griliches (1980) /

(1980b) however, in line with Waterson and Lopez, suggests that capital intensive firms with large plants tend to invest more in R & D.

The second variable used to approximate technological opportunity, technical progress or growth in output per head seems a result rather than a determinant of research intensity. However again the product cycle theory suggests that at very high levels of productivity the opportunities for technological breakthroughs will have been exhausted.

5.3 <u>The Influence of Firm Size</u>

A considerable amount of effort has been devoted to testing the relationship between firm size and the incentive to invent or innovate. This may be due to the implications the Schumpeterian hypothesis has for government anti-trust policy. If larger firms devote proportionately more of their resources to R & D or more significantly if they produce proportionately more inventions and innovations than smaller firms, then anti-trust policies could be damaging to dynamic efficiency in an economy.

This section of the chapter, which reports the existing empirical evidence concerning the influence of firm size on inventive activity, is divided into two parts. In the first part those studies which concern the relationship between R & D inputs and firm size are described, while in the second part studies which concern the relationship between inventive outputs and firm size are reviewed. From the point of view of this thesis, in /

in which patent data is used as an index of inventive output, the second group is more important. However, because R & D inputs have been shown to be positively related to R & D outputs (see section 1.4), the results of the two types of studies are as expected, very similar. While most of the empirical tests completed have been on U.S. data, a number of U.K. studies are highlighted in the discussion. In the second part of the section, work by Mansfield and others (1977a) is discussed at some length due to the separation of process from product innovations, which again is of interest to this thesis.

Firm Size and R & D Inputs Early U.S. tests of the relationship between firm size and R & D effort, by Worley (1961), Horowitz (1962) and Hamburg (1964), provide no evidence that effort devoted to R & D increases more than in proportion to firm size. Hamburg (1964), whose early work is often referred to, gathered data on 340 large U.S. firms in 19 two digit manufacturing industries to test the relationship between industrial R & D activity, in both the absolute and relative sense, and firm size. Using rank correlation analysis for each of the 19 industries, he found that the absolute level of R & D employment tended to increase with firm size in all but one industry. But when logarithmic regression analysis was used, Hamburg found that R & D intensity increased with firm size in but two industries, petroleum and stone, clay and glass. In one industry, primary metals, the coefficient for size /

size was significantly less than one.[1]

Results reported by Mansfield (1964) generally confirm Hamburg's conclusions concerning R & D intensity and firm size. Mansfield estimated the elasticity of R & D expenditure with respect to firm size on major U.S. firms in the chemical, petroleum, drug, steel and glass industries. His least-squares estimates show that except for chemicals, the largest firms in these industries seemed to spend no more on R & D relative to sales than smaller firms.

Mansfield (1964) also provided a test of the economies of scale in R & D activity in the U.S. chemical, petroleum and steel industries. Tapping various data bases, he measured the effect of R & D expenditure on the number of inventions or innovations made by firms weighted by their importance in each of the three industries. Holding R & D expenditure constant in a regression analysis, Mansfield found the effects of firm size on the average productivity of such expenditure to be negative in each industry and statistically significant in two of the three. Mansfield attributes this to looser controls and the greater problems of supervision and co-ordination in /

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1. Scherer (1965b) suggests that Hamburg dismisses coefficients too quickly when they do not meet the .05 significance test. He points out that eight of eleven major two digit industries in Hamburg's tests have size coefficients greater than one, when employment is the size variable, even though they only pass significance tests at the .10, .20 or .30 levels.

in a very large organisation. Holding firm size constant, the evidence suggests that increases in R & D expenditures result in more than proportional increases in inventive output in the chemical industry. This is not true of the other two industries. Summarising his findings, Mansfield (1964) states that the results imply no marked advantages of the largest-scale R & D activities over large and medium-sized ones.

Scherer (1965a), in evaluating empirical work concerning firm size and R & D intensity, notes that the logarithmic equations used by Hamburg (1964) are unable to detect such structural features as inflection points. Scherer, therefore, using R & D employment data from 352 of the largest 500 U.S. firms in terms of 1955 sales, regresses R & D employment on linear, squared and cubed sales variables. In addition, to suppress the influence of giant corporations, he regresses R & D employment on the logarithmic transformation of all three sales variables. Scherer's results show R & D employment intensity increasing with size among firms with sales of less than \$500m, but declining among firms with sales over this amount.

Classifying firms into six, two digit SIC industries, Scherer (1965a) conducts separate regressions for each one. In nearly every case the equations with logscales show increasing intensity among the smallest and medium size firms. Both untransformed and log equations show research intensity /

intensity declining with size among larger firms in the non-chemical group. The chemicals industry, however, displayed research intensity continuing to increase with firm size or sales. Scherer cautions that his industry results can only be viewed as 'best' estimates due to the three sales variables being highly collinear. He notes however that the results are similar to those of Mansfield (1964) and his own corporate patenting analysis, which are described in the section dealing with size and research outputs. More recently Scherer (1980, p.420) has reported that the difference once apparent in the chemical industry appears to have disappeared over time. In data for U.S. firms in 1975, there was no evidence of a positive correlation between R & D/ sales ratios and firm size among 54 industrial and specialty chemicals producers.

Scherer (1965a), also in his early article, pointed to a number of the problems involved in estimating the relationship between firm size and inventive activity. One such problem is that of zero values for either firm R & D input or output data. He suggests that when zero values exist in the relevant population the logarithmic test of the size variable on R & D inputs, both dependent and independent variables transformed, is not valid. If the tendency is for the smaller firms in any distribution to undertake no R & D, leaving these firms out of the regression, which is necessary under the logarithmic form, may result in underestimating the influence of firm size. /

size.

Scherer (1965a) further discusses the effects of using different measures of firm size on regression results. He concludes that the sales measure is preferable to either employment or assets because it is neutral in terms of factor proportions. He suggests that the most suitable measure would be value added, but notes that data is seldom available for individual firms.

Additional U.S. results provided by Comanor (1967), Mueller (1967) and Grabowski confirmed the earlier findings. Grabowski (1968), for example, compared the influence of firm size in the U.S. chemical and drug industries on R & D expenditure by large firms (on the 1960 Fortune's 500 listing). He uses a quadratic regression equation, estimating parameters for both linear and squared values of sales, to determine the effect of size on research intensity in the two industries. The results from 1959-62 data show quite different behaviour in the two industries. For chemicals, the statistically significant sales parameters indicate that research intensity increases continuously with firm size. For drugs the coefficient of the squared variable is significantly negative. A plot of the estimated relationship, indicates that after a brief initial increase in research intensity with size, research intensity decreases with size throughout most of the range.

Grabowski (1968), in the same study, examines the relationship between firm research productivity and firm /

firm size, stressing the importance of the relationship to any argument for corporate bigness. Research productivity is measured here by the number of patents received per scientist and engineer employed over a four year period. He finds weak, and in the case of the chemical industry negative and insignificant correlations between the variables, lending no support to the aforementioned argument.

More recent studies of R & D effort and firm size provide mixed results. Rosenberg (1976) tested the size hypothesis using 1963 market share as a measure of size in 100 large U.S. firms. He reported that the percentage of a firm's 1964 total employment allocated to professional R & D personnel declined as market share increased.

Shrieves (1978) also using mid-1960's data, tested the influence of the logarithmic transformation of sales on the logarithmic transformation of privately financed R & D employees for 411 U.S. firms included in the publication, Industrial Research Laboratories of the United States. A number of other variables were also included in the regression equation. Shrieves finds the sales parameter to be significantly (.01 level) less than unity (.604) implying that smaller firms that perform R & D allocate proportionately more resources to R & D than larger firms.

Griliches /

Griliches (1980b)using a sample of 883 large (having over 1000 employees in 1964) and R & D performing U.S. firms found no evidence of anything more than a proportional relationship between R & D (total accumulated R & D expenditure, 1957-65) and size (average of 1957 and 1963 valued added).

In contrast to most of the empirical work, Soete (1979), using 1975 and 1976 company financed R & D expenditure data for over 500 U.S. firms,[1] found that innovational effort increased more than proportionally with firm size. This result was consistent regardless of the method of analysis - concentration ratios, logarithmic or cubic regression. Soete could draw no general conclusions however when analysing the data by industrial group.

Perhaps as important as Soete's results is his critical analysis of previous empirical studies testing the relationship between firms'size and R & D effort. He argues that much of the data used in previous studies is from the mid-1960's and before and therefore obsolete. Soete comments that important changes in firms'size have occurred over the last 10-20 years. He adds that R & D employment data and patent data, which have been the major /

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1. Soete's R & D expenditure data is taken from the Business Week Survey covering 95% of total company financed R & D expenditure in the U.S. Since 1976 Business Week has published this data for individual firms.

major indicators of inventive activity, overestimate the contribution of the smaller firm.[1] He suggests that R & D expenditure is a more 'neutral' measure. Finally he criticises previous studies for lacking any theoretical justification for their findings. Soete asks why large firms fully exploiting economies of scale in other areas, such as marketing, would fail to do so with regard to innovational activity.

Studies done using non-U.S. data show a less than proportional relationship between R & D intensity and sales, with a few variations. Adams (1970) for example concluded that the effect of increased seller concentration in the French economy, in the form of large firms, is likely to have a perverse effect on the volume of French industrial R & D activity.

Caves and Uekusa (1976) report on Uekusa's study on the relationship between R & D expenditures and firm size for a sample of nearly 300 large manufacturing and construction firms in Japan. For the entire sample, regression analysis for separate years (1965, 1967, 1969) implies that R & D expenditure rose more or less proportionately with size to a certain point but then decreased absolutely. These results change however, when the firms are divided into industries. In highly innovative industries /

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1. Soete cites evidence showing that R & D costs per scientist and engineer increase with firm size and that large firms patent a smaller proportion of what they invent.

industries, R & D expenditures are found to increase more than proportionately to firm sales. In moderately innovative industries the increase is more than proportional only up to a point, then becomes less than proportional and ultimately declines absolutely. In the less innovative industries the increase in R & D becomes less than proportional for those with more than a modest volume of sales, and again an absolute decline ultimately sets in.

A recent paper by Waterson and Lopez (1983) suggests that firm size has virtually no influence on R & D intensity in the U.K. among firms with R & D programmes. They come to this conclusion by estimating the relationship between industry-level R & D intensity (R & D expenditure as a percentage of sales in 1975) and average industry firm size, in fifteen Minimum List Headings industries. The regression equations also include independent variables representing technological opportunity and concentration. Waterson and Lopez find that average firm size appears to have a negative influence on company financed R & D as a percentage of sales and no significant influence on total R & D intensity.

In further regressions, using pooled industry data from 1972, 1975 and 1978, Waterson and Lopez adopt a logarthmic equation to test the form of the relationship between company-financed industry R & D expenditure and average firm size. The coefficient for size is significantly /

significantly less than unity (.792) implying a less than proportional relationship between the two variables. However, due to the correlation between average industry firm size and concentration the authors state that conclusions are hazardous in this respect. When the concentration ratio is adjusted to account for foreign trade, the correlation between concentration and firm size declines and the coefficient for average firm size becomes slightly greater than one retaining its significance. As an overall conclusion Waterson and Lopez state that amongst relatively large firms, those in industries which are more concentrated and having larger firms are not on average heavier spenders than those in unconcentrated industries with relatively small firms.

<u>The Relationship of Firm Size to Inventive Outputs</u>

An important early test of the effect of firm size on the generation of inventive outputs was that by Scherer (1965a). Scherer observed, from fully comparable data on 352 U.S. firms, that sales volume among firms was more concentrated than R & D employment, which itself was slightly more concenrated than patenting. The implication was that both inventive inputs and outputs increase less than proportionately with sales and that inventive outputs increase less than proportionately with inputs. In the same study, Scherer (1965a) conducted a more formal nonlinear regression analysis between firm patenting in 1959 and firm sales in 1955, using data from 448 large U.S. corporations. Regressing firm patenting activity /

activity on the first three powers of sales, Scherer found: a significant and positive coefficient for the first power; a significant and negative coefficient for the second power; and a positive coefficient for the cubic power, but with doubtful significance. More precisely Scherer found diminishing returns dominating up to a £5.5 billion sales level, after which increasing returns set in. Only three firms however, had sales over this amount. When Scherer (1965a, p.1108) repeated his tests, breaking the same firms into both fourteen industry groups and four consolidated groups, he came to the same conclusion, 'again the indication is one of diminishing returns except for a few giants leading their two digit industries.'

Mansfield (1963, 1971, 1977) has used a standard format to analyse the relationship between firm size and important innovations introduced, in a number of studies for different industries over various time periods. His database in all of these studies is composed of important innovations in the industry as listed by trade journals, trade associations, university departments and the firms themselves, associated with the particular industries. The sources were asked in addition to rank each innovation by its importance, as measured by either cost savings for process innovations and volume of sales for product innovations. The innovations were then traced to the originating firms.

Mansfield, and in some studies his fellow authors, first /

first examine the share of innovations accounted for by the largest four firms in an industry as compared to their market share. Then shifting to the full range of firm sizes, regression analysis is used to determine the optimum firm size in each industry with respect to maximising the rate of innovation.[1]

Early work by Mansfield (1963) in this area focused on three industries, iron and steel, petroleum refining and bituminous coal. Results showed that in two industries, petroleum refining and coal, the four largest firms introduced a larger share of innovations than their share of the market. However in steel the four largest firms introduced a disproportionately small share of innovations. In a simple regression model to determine why giant firms had a greater impact in some industries and not in others, Mansfield found that the investment required to use potential innovations relative to firm size was a good predictor.

In /

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1. Mansfield's (see for example Mansfield, et.al. 1977 p.51) regression equation is as follows:

$$N_i = a_o + a_1 S_i + a_2 S_i^{\,2} + a_3 S_i^{\,3} + z_i$$

where N_i is the number of innovations weighted or unweighted; S_i is a variable representing firm size; and z_i is a random error term. After the equation is estimated, N_i/S_i is solved for and its maximum value determined.

In his analysis over the entire range of firms, Mansfield found that the sixth largest firm introduced maximum innovations relative to its size in both the petroleum and coal industries. In steel the optimal size was found among very small firms. Mansfield cautions however, that his regression equations fit the data only moderately well.

A further test made by Mansfield (1963) in the same study, and one of particular relevance to this thesis, involved the separation of process and product innovations in the steel and petroleum industries. After regressing firm size individually against the number of product and process innovations made by firms in each industry, he compares the resulting residuals, finding them weakly correlated. Mansfield's (1963, p.566) conclusion is that 'holding firm size constant, a firm that did considerable innovating with regard to process also did considerable innovating with regard to products.' This piece of evidence is not consistent with the hypothesis that firms 'trade-off' process innovations against product innovations (see, for example, Wilson, 1977).

In a later study of the U.S. ethical drug industry, Mansfield et.al. (1971) follow the same format as that described above. They concluded that, if innovations were not weighted by their importance, the four largest firms were responsible for a relatively smaller share of innovations than their market share. However, when innovations /

innovations were weighted by their importance, the share of innovations carried out by the largest four firms was equal to their share of the market. The twelfth largest firm in the pharmaceutical industry was found to introduce the greatest number of innovations relative to its size.

In their following study of the U.S. chemical industry, Mansfield et.al. (1977b) include not only those firms first using major innovations in their database, but also those firms responsible for the development (or in the terms of this thesis - production) of the innovations. The first commercial user and the developer may or may not be the same firm. They also separate major innovations into process innovations and product innovations, which although in only one industry, provides a useful basis of comparison for this thesis.

In their analysis of the largest four firms in the chemical industry, Mansfield et.al. (1977b) found that with respect to process innovations, either unweighted or weighted by importance, that the asset share of the largest four firms exceeded their share of innovations. The largest four firms however accounted for the same share of process developments as they did of the industry's assets. Using regression analysis on the full range of firm sizes, the authors found that the firm size generating the maximum rate of innovation occurred among very small firms for first users of innovations and at about the seventh /

seventh or eighth largest firm for developers of innovations, whether the data was weighted or unweighted.[1] They concluded that there was no tendency for the very largest firms to carry out a disproportionately large share of process innovations or developments.

Results of the study were substantially different for product innovations. Breaking the period over which major innovations had been counted 1930 to 1966 into two time periods 1930-1950 and 1951-1966, Mansfield et.al. (1977b) found that the four largest chemical firms carried out a larger share of product innovations and developments than their share of the industry's assets in the later period, but not in the earlier period. Comparing these results with earlier studies, the authors conclude that the largest four chemical firms made a larger impact on product innovation than those in the steel and ethical drug industries and about the same as their counterparts in the petroleum industry. Using the full range of chemical firms in regression analysis, the maximum value of both innovations and developments relative to firm size occurred in the largest firm in the industry, du Pont. This was true for both weighted and /

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1 . These results were obtained using data on major chemical innovations between 1951 and 1971. For an earlier time period, 1930 to 1950, all relevant sizes of firms carried out the same number of process innovations relative to their size (see Mansfield et.al, 1977b,p.52)

and unweighted data and for both time periods used.

In concluding remarks concerning their study, the authors point to the much greater role for the largest chemical firms in product innovation as opposed to process innovation. Their results for product innovation are also consistent with evidence indicating that the chemical industry is the one major industry where the largest firms spend proportionately more on R & D relative to their size than smaller firms. The authors (Mansfield et. al. 1977b,p.64) add the following with respect to the differences between product and process innovation results:

> To a considerable extent, this difference undoubtedly reflects a conscious policy decision at du Pont concerning the areas and types of work that it regards as most profitable. New products like nylon or orlon can be enormously profitable if a firm is able to overcome the many technical and commercial hurdles that lie along the road to success.

Discussing all of their evidence more fully, the authors also note that innovations in the chemical industry were not generally introduced and developed by the same firm. However as firm size increased, the likelihood that developer and innovator would be the same firm

also /

also increased.

Evidence concerning the relationship between firm size and inventive output in the U.K. is supplied in a study by Smyth, Samuels and Tzoannos (1972). More specifically the study examines the relationship between a firm's size, its profitability, its liquidity and the number of patented inventions it produces, for three industries - chemicals, electrical and electronic engineering and machine tools. Drawing a sample of 86 U.K. firms from Kelly's Directory of Companies, the authors regress number of firm patents, 1963-1966, on the first two powers of firm size, as measured by assets, 1963. Results which showed chemical patenting to increase more than proportionately with firm size, were similar to those in the U.S. In electrical engineering and electronics the authors report that patenting increased more than proportionately with firm size, but that this did not hold true for very large firms - GEC, Associated Engineering. In machine tools the authors found that smaller firms patent more than larger firms.

5.4 /

5.4 The Influence of Market Structure

As indicated in the corresponding theoretical section, market power has two offsetting influences on technical knowledge production by the firm. The absence of competition implies greater monopoly profits from the commercialisation of a firm's inventions; however, it may also lead to complacency in innovation due to a lack of pressure from rivals. Empirical tests are of interest here in determining the relative strength of what Scherer (1980, p.429) refers to as two clashing 'structural propensities'.

A frequent test of the influence of market structure on inventive activity is one analysing the relationship between inventive inputs or outputs in a firm or industry and its industry concentration ratio. Results of such tests are reported in the first part of this section. In addition, the few studies concerning the relationship between inventive activity and industrial entry barriers are also described. An early study by Comanor (1967) which indicated that there may be a complex relationship between inventive activity and concentration is highlighted as well as a later study by Shrieves (1978) which also follows this line. In the second part of the section results concerning the relationship between profitability and liquidity, two other indicators of market power, and inventive activity are reviewed. The great majority of empirical studies in this area are from the U.S.; very/

very little work has been done using U.K. data.

Studies Testing Industrial Concentration In two earlier U.S. studies conducted along this line, Horowitz (1962) and Hamburg (1966) both found positive correlations between industry R&D intensity, as measured by R&D expenditure to sales, and industry concentration ratios. In both studies, however, the association found between the two variables was weak. As Scherer (1965a) notes, a deficiency of these earlier studies was the failure to take interindustry differences in technological opportunity into account.

Scherer (1965a), who has done considerable work in this area, first found, in a study of the effect of concentration on the patenting output of 448 U.S. companies, that inventive output did not appear to be systematically related to market power. However, in a slightly later study (Scherer, 1967) using inventive inputs rather than output as a measure of technological change, he concluded that there was some support for concentration as a positive influence on inventive activity, although the relationship was complex.

Scherer (1967), using data on 56 U.S. industries, found a simple correlation of positive 0.46 between the ratio of scientific and engineering workers to total employment in an industry and the industry concentration ratio. When differences in industry product technology were taken into account, however, the partial correlation coefficient between the technological employment index and concentration/

concentration fell to 0.20. The fall in the coefficient was attributed by Scherer to the positive correlation between technological opportunity and concentration, and the strong correlation between technological opportunity and industry inventive intensity.

A study of considerable importance, which highlighted the 'complex' relationship between concentration and innovative effort was that of Comanor (1967). Comanor, who set out to investigate the various dimensions of market structure on the level of research, considered product differentiation as a strong incentive to allocate funds for research. He found that there may be an important interaction between concentration and product differentiation in their influence on research spending. His analysis was based on a sample of U.S. firms in 33 three digit SIC industries, which were classified into two sectors: those producing investment goods and consumer durables and those producing material inputs and consumer non-durables. The first sector was characterised by industries in which product differentiation played an important role in market behaviour while in the second sector product differentiation was relatively weak. Comanor's results showed that while average research levels in both sectors tended to be higher when concentration was higher, the relationship was far stronger in industries where prospects for product differentiation were weak. From this Comanor concluded that where research is more closely tied to competitive conditions, increased concentration is less likely to lead to higher levels of research. He warns that due to his exclusion of the technological/

technological opportunity variable, the influence of concentration on research might be overstated in his results. This, Comanor notes, is because technological factors tend to be positvely correlated with concentration.

Comanor (1967), in the same study, regressed industrial research levels against a number of entry barriers, including one for product differentiation. He used a dummy variable for product differentiation based on the same two sectors previously mentioned. He concluded from his results that industrial research appears strongest in industries where some measure of technical entry barrier exists, so that rapid imitation is impeded - but also where entry has not been effectively foreclosed.

Rosenberg (1976), following up on the Comanor test of the influence of entry barriers on innovative activity, analysed the effect of advertising intensity, capital intensity and economies of scale on the percentage of total employment allocated to professional R&D employment in 100 U.S. firms. He found that entry barriers were a positive but not significant effect on research intensity. Rosenberg concluded, however, that entry barriers may be somewhat more important than previously assumed. Rosenberg also found that market share and industrial concentration have a significant impact on R&D intensity, although the influence of a firm's market share is negative. His study indicated that concentrated industries with firms of equal size (market shares) would be most R&D intensive.

Shrieves/

Shrieves (1978, p. 330), following the work of Scherer and Comanor, offers what he views as a 'more definite view of the dichotomous nature of the relationship between market structure and the intensity of innovative effort'. Using a sample of 411 U.S. firms, he conducts multiple regression analysis to estimate the relationship between concentration levels across industries. He accounts for product market characteristics, technological characteristics, and government involvement in generating technology in his analysis.

Shrieves first estimates the relationship between innovative effort and the concentration aspect of market structure across industry groups without regard to the potential dichotomous nature of the relationship suggested by earlier studies. His concentration ratio has a positive and significant regression coefficient which offers support for the thesis that firms in more concentrated industries are more vigorous innovators than firms in less concentrated industries.

Analysing his data further, Shrieves (1978) partitions his sample of firms by product-market characteristics, allowing a four-way classification of industries. His classifications are not subjective, but result from input-output data on sales of consumption goods, investment goods and naterials for all 53 three digit industries into which the 411 firms were classified. Regression results by sector show that the role of concentration as a stimulus to/

to research appears to be ambiguous, very much depending on the product types sold and markets served by an industry. While concentration levels were significantly and positively associated with R&D effort for material inputs and consumer goods producers, the relationship was marginally significant and inverse for specialised durable equipment. A positive but marginally significant relationship was also found between concentration and research effort for producers of non-specialised producer goods.

Shrieves' results lend support to Comanor's theory of a dichotomous role for concentration as an influence on research effort. His results also suggest that concentration may have an adverse effect on innovative efforts in certain industries, although findings are not strong in this respect. He also concludes from his analysis that product differentiation (as stressed by Comanor) may not be the only or best explanation for the dichotomous role of the concentration variable. His data show certain technological characteristics to correspond with product market characteristics in the durable goods as opposed to the material inputs and consumer products sectors. In the latter sector firms are larger and the technology is more concerned with the life sciences and chemistry and more process oriented. In the former sector, however, firms are smaller and less process oriented, while the technology is heavily oriented towards/

towards electronics, aerospace, mechanical and electro-mechanical fields. Shrieves emphasises the interaction of these characteristics as an alternative explanation for the dichotomous role played by concentration in innovative effort.

There is remarkably little evidence on the relationship between market structure and innovation in the U.K., although Waterson and Lopez (1983) do consider this in a recent study. Their conclusion is that R&D intensity does not appear to be positively associated with concentration within 15 of the most research-intensive industries in the U.K., once technological opportunities and statistical difficulties have been taken into account.

A problem faced by Waterson and Lopez in their industry-level study is the limited amount of data on R&D expenditure and employment available in the U.K. Data is compiled at approximately three-year intervals for about 15 broad industry categories with minimum list headings, which as the authors note, over-represents the more research-intensive industries. While they alleviate the problem somewhat by increasing the sample, combining information for more than one year, they are still left with broad industry categories for which the meaningfulness of concentration ratios must be questionable.

Using the combined data for company financed R&D only, Waterson and Lopez find that concentration has a mild impact on industrial R&D as a percentage of sales when/

when average firm size and technological opportunity were accounted for. The authors, however, question the results on the basis that concentration is simultaneously determined along with R&D expenditures in the long run, rather than causing a certain level of R&D. Using an instrumental variable, an index based on minimum optimal scale of production in an industry, to solve the simultaneity problem and represent concentration, in a further test they find that the concentration index becomes almost insignificant. Also, when a measure of concentration is used which is adjusted for foreign trade, the concentration variable loses its significance as a determinant of R&D intensity.

Studies Concerning Profitability and Liquidity

In contrast to the use of concentration ratios as a measure of market structure, several studies have included measures of liquidity and/or profitability as determinants of inventive or innovative activity. As Mueller (1967) notes, profits serve a dual role in determining the inventive effort made by firms. Current profits are both a flow-of-funds and an indication of future returns from similar investments. Both of these aspects support the hypothesis that firms in more concentrated industries are more likely to be innovators. An alternative view is that profits may be inversely related to inventive activity, as firms suffering a decline in profits may be forced to innovate to survive.

Empirical/

Empirical tests of the relationship between inventive or innovative effort and either liquidity or profitability have generally shown a weak relationship (for example, see Scherer, 1965a and Hamburg, 1966). However, there have been some positive results and other results of interest.

Grabowski (1968) found liquidity to be a positive and significant influence on firm R&D intensity in his study of the U.S. chemical, drug and petroleum industries. As a liquidity measure, Grabowski uses the sum of a firm's after-tax profits plus depreciation and depletion charges. In another study with Baxter (Grabowski and Baxter, 1973), further support was found for the influence of internally generated funds on R&D. Using data from eight U.S. chemical firms over the period 1948-1967, the authors estimate the annual changes in firm R&D expenditure. In multiple regression analysis, they found cash flow to be the single most important explanatory variable in their equation.

Mueller (1967) tests a simultaneous firm-decision making model concerning four variables, R&D expenditure, capital investment, advertising and dividend payments using observations from 67 U.S. firms over four years. For the equation explaining R&D intensity (R&D expenditure deflated by sales) he found the depreciation coefficient to be positive for all years but significant for only one recession year. He concluded that its increased strength of influence in that year, coupled with its low coefficient/

coefficient in the investment equation for the same year indicated a shifting of resources from investment to R&D in years when the returns on the former activity are low. His view therefore of R&D is one of less cyclical influence than that of capital investment. Mueller also finds an increased importance for profits as an explanatory variable in years of high economic activity. He states that in peak years when expectations are most buoyant, high returns to the extent that they are attributed to past R&D have their strongest impact on firm decision making.

Elliott (1971) in a U.S. study using a cross-sectional sample of 53 firms drawn from 16 industries, sets to examine the rate of profits either as a demand variable or a flow-of-funds variable in its relationship to firm R&D spending. He proceeds by developing a stock-adjustment model of R&D investment spending, where current spending depends on the difference between a desired 'technology stock' and the firm's actual stock. Along with variables representing the external industry environment, Elliott includes three firm profit measures and two measures of firm liquidity to represent internal determinants of R&D. His findings show that there is consistently stronger support for the profit role as an expectational influence on R&D than for the funds-flow effect. This is because those profit measures which are most significant in his regression equation, are interpreted as measures of expectations.

A/

A more positive result was obtained by Branch (1973), who examined 111 U.S. manufacturing corporations in industries where appreciable amounts of privately supported R&D were performed. Estimating distributed lag functions for pooled company time-series data by industry, he found support for both causal flows from profitability to patenting and from patenting to subsequently increased profits. Of the two the chain from profitability to patenting was less consistent and statistically weaker.

In the U.K. Smyth, Samuels, and Tzoannos (1973) have tested the effect of profitability and liquidity on the number of patents obtained by 86 firms in three industries, chemicals, electrical engineering and electronics and machine tools. The average five year profit rate had no significant effect in any industry. Cash flow, measured by undistributed profits plus depreciation had a positive effect in each case but it was significant only for chemicals and machine tools.

A problem in using profits or liquidity as proxies for concentration is that they are not direct measures of market structure. They may be the results of a concentrated market structure, but even this is not certain. Profits may be high in a new industry which is rapidly growing or may be the reward for exceptional management. It is difficult, therefore, to arrive at conclusions concerning the effect of market power on invention from studies using these proxies.

5.5/

5.5 The Influence of Technological Rivalry

Although it is a characteristic of market structure, technological rivalry is important enough to consider individually as an influence on technological changes made by firms. The hypothesis here is that competition in the form of technological product differentiation acts as a stimulus to firm inventive and innovative activity. Scherer (1967, 1980) predicts that an increase in the number of firms up to some point of overcrowding should be a positive influence on invention and innovations. Grabowski (1973, 1978) suggests that oligopoly is the market form most conducive to rivalry.

While a good deal of theoretical work has been done on the influence of technological rivalry (see Kamien and Schwartz, 1982), little has been accomplished in terms of empirical studies. Rivalry is used to explain particular empirical results concerning the influence of market structure in general on the research intensity of firms, however it is only rarely directly measured. A number of studies have used dummy variables to represent the ease of product differentiation in an industry, however these may be as suggestive of opportunities available than actual rivalrous conditions.[1] Grabowski in the U.S. has made the /

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1. While Comanor's (1967) view of product differentiation has been generally linked with technological opportunity, Comanor himself stressed that new product development may be a major source of rivalry in some industries. See section 6.2 for a discussion of Comanor's work.

the most significant contribution in terms of measuring rivalry in a more direct manner.

Grabowski and Baxter (1973) in their investigation of eight U.S. chemical firms over the period of 1948 and 1967 tested the hypothesis that one determinant of changes in firm R & D expenditures is previous changes in its rival's R & D expenditure. The chosen rival in their study was determined by best statistical fit as either the leading R & D spender or the immediate successor in terms of R & D expenditure. While the single most important determinant of firm R & D expenditure in the study turns out to be the firm's cash flow, the previous changes in rival firm R & D was significant in four out of eight cases. Previous changes in the firm's own R & D expenditure was a significant explanatory variable in three cases.

In the same study, Grabowski and Baxter (1973) test the relationship between competitive reaction in terms of R & D and industrial concentration. They hypothesise that the incentive to compete by differentiation and improving product lines through R & D rather than by price changes, should be stronger in more oligopolistic industries. Grabowski and Baxter measure R & D competitive reaction by the coefficient of variation in industry research intensity. They predict that as the strength of reaction becomes larger, a greater conformity in the level of R & D inputs should be expected. Using a sample of twenty-nine U.S. industries /

industries and an eight firm concentration ratio, they found a significant and negative relationship in the rank correlation between concentration and the coefficient of variation of research intensity. They concluded that concentration does lead to greater conformity in R & D spending, although as Kamien and Schwartz note (1982) this has no implication for the level of industrial R & D spending.

While a number of British economists, including Freeman (1982) and Pavitt (1980) have stressed the importance of technological competition or rivalry in understanding patterns in R & D expenditure and successful economic performance, there has been an absence of empirical tests along the lines of Grabowski and Baxter.

5.6 The Influence of Diversification

As explained in section 4.6, a firm's degree of diversification might be expected to have a positive influence on its incentive to invent. This is because of the higher expected profitability from research for firms with diverse product lines, able to make use in some way of the unanticipated results of their research efforts. Also, if R & D projects are conducted in a number of the firm's product areas, lower average risks of technical and commercial success may be a result.

Although the argument has greater validity for basic research leading to scientific discovery than applied /

applied research leading to new technical knowledge, the diversification hypothesis has been tested on the incentive to conduct R & D generally. Scherer (1965a) compiled an index of product line diversification for each of 463 U.S. firms on Fortunes's list of the 500 largest industrial enterprises, measuring the number of technologically distinct product lines out of a possibility of 200. A diversification index was then introduced into regression equations relating 1959 firm patenting to 1955 firm sales for 14 broad industry categories and similar equations relating 1955 R & D employment to 1955 sales for seven two-digit industry groups. Scherer found positive and in some instances highly significant partial correlation coefficients between diversification and inventive activity in a number of industry groups which in general did little R & D. However, in interpreting this finding Scherer did not view diversification as a stimulus to research, but as a structural indicator that firms were looking for richer opportunities for pursuing research and developing new products. Negative and statistically unsignificant results in the electrical equipment and chemical and drug groups, led Scherer to conclude that there is little evidence that diversification is conducive to especially vigorous R & D activity.

Comanor (1965), in his study of 57 U.S. pharmaceutical manufacturers, found the index of firm diversification to be inversely correlated with R & D productivity or new /

new drug product sales in the first two years after introduction. Here the diversification index was measured by the firm's participation in forty therapeutic markets defined on the basis of the apparent medical useage. Comanor concluded that inefficiencies can result when a firm spreads its research efforts too thinly over many lines.

Grabowski's results (1967) were somewhat more positive concerning the diversification hypothesis. Examining U.S. firms in the chemical, petroleum and drug industries, in all three groups he found R & D spending as a percentage of sales to increase with the number of five-digit product lines in which the firms operated. The coefficient for diversification however, was only significant in the chemical and drug sectors.

In a more recent study, Link and Long (1981), criticise previous empirical work which mis-specifies the original diversification hypothesis of Nelson, which was related to basic research rather than total R & D. They correct this error by testing the influence of firm product diversification (the number of four digit industries in which the firm operates) on the basic research intensity (basic research spending as a percentage of sales) of 250 U.S. manufacturing firms. Accounting for a number of other influences on basic research, Link and Long find the coefficient for diversification to be positive and statistically significant at the .05 level.

In /

In conclusion, it can be said that while there is some U.S. support for diversification as an influence on basic research, there is little support for its contribution to the production of technical knowledge. In the U.K. there have been no statistical tests upon which to make a judgement.

5.7 The Influence of Factor Costs

It has been hypothesised (see section 4.7) that firms will have a greater incentive to produce new knowledge related to production processes, the more factor prices change. This is because as input prices go up, firms act defensively and increase research on production techniques in order to preserve profit margins over time.

While a number of U.S. studies (see for example Fellner, 1971, and Binswanger, 1974) have attempted to estimate the influence of factor price changes on the bias of inventive activity, or in other words to test the Hicks induced invention hypothesis, little effort has been made to test the effect of factor price changes on the overall level of inventive activity. However in a recent study of Schmookler's demand pull hypothesis, Scherer (1982) extends his analysis to include a number of other possible influences on patenting activity. He hypothesises that one influence on the efforts toward labour-saving capital goods inventions might be an unusually rapid increase in wages. To test his /

his hypothesis, Scherer estimates the reaction of capital goods patents classified by industry of use to the percentage change in using industry worker wage payments over five years and to two measure of demand-pull influences. Using a sample of 443 large U.S. corporations in 245 industries, his tests reveal no stimulating role for rapid wage increases in using industries.

5.8 Influence of the Product Cycle

The product cycle hypothesis, as it relates to innovation, predicts that the stage of development reached by a productive segment has a strong influence on its propensity to host particular types of innovations. Product innovations are expected to be dominant at the early stages of the cycle, with attention to process innovation following when production cost reduction becomes more important. This leads to a related hypothesis (see Wilson, 1977) that firms will 'trade-off' product innovations against process innovations. At the mature stages of the cycle, inflexible capital intensive production methods make both types of innovations very costly.

Although there have been a number of case studies stressing the influence of the product cycle on innovation, variables representing the stage of development have not been included in econometric tests at the firm or industry level. In a few studies, for example, Griliches (1980) /

(1980b) and Waterson and Lopez (1983), capital intensity has been used as a variable, but it has not been linked to the stage of industry maturity. In both studies capital intensity is found to increase innovative effort, which is contrary to the product cycle hypothesis.

As was previously mentioned (see section 6.3), in the only empirical test related at all to the 'trade-off' theory, Mansfield (1963) found that firms that did considerable innovating with respect to process also did considerable innovating with respect to products.

5.9 Summary

Generalising, with respect to the major variables which have been tested it can be concluded that both demand and technological opportunities available to firms influence inventive and innovative activity. More work is needed however, to find proxies which more closely fit the technological opportunity variable. While inventive activity has been found to be associated with firm size, most evidence shows the relationship to be less than proportional, except in the chemical industry. A recent study however has challenged some of the earlier results on firm size. As far as industrial concentration is concerned, U.S. economists have suggested a complex relationship between market structure and innovation. The issue has not been pursued to any extent by U.K. economists. While there is less evidence available on these variables, there appears to be a role for /

for technological rivalry in influencing inventive decision-making but not one for either firm diversification or changing factor input prices. While the product cycle hypothesis has been given some attention at the theoretical level, it receives little more than a mention at the empirical level.

While this thesis will not attempt to fill all of the noted gaps in empirical knowledge, hopefully the study will add to the understanding of inventive activity among U.K. firms. Clearly evident from the preceding discussion is the dearth of studies using U.K. data. Also, taking account of Stoneman's (1983, p.46) criticism that most empirical work in the area is based on 'ad hoc theorizing', this thesis proceeds by first developing theoretical models of inventive activity and then applying empirical tests to these models. The theoretical models are developed in chapter six. The thesis also adds to the small amount of work done on distinguishing influences on process inventions from those on product inventions.

CHAPTER SIX

THEORETICAL MODELS OF PROCESS AND PRODUCT INVENTION

In this chapter a number of firm decision-making models with respect to invention are developed. These models point more precisely to some of the general theoretical predictions discussed in chapter four. They also serve as a basis for the empirical work in chapter eight.

The procedure will be to develop separate models for process and product invention and to compare their characteristics. A model which combines the two types into the total patenting activity of the firm will also be presented. The assumptions and technique used are eclectic, drawing from a number of sources. The recent work of Stoneman (1983) however is especially helpful. There are also some additions to fit the purposes of this thesis. The development of the models proceeds from the simplistic to the slightly more complex and realistic.

6.1 Basic Assumptions

It is assumed that the firm produces output (Q) using the traditional inputs of labour and capital and also its existing stock of technical knowledge (A). In order to focus on the technological input, we assume that capital and labour are used in fixed proportions as a composite input (L). Therefore:

$$[6.1] \quad Q = g(A,L)$$

Technical /

Technical knowledge not only affects the output which the firm produces but also the firm's production costs. Process inventions lower costs to the firm, increasing the productivity of the conventional factors. Therefore we also have:

$$[6.2] \quad C = h(Q,A)$$

where C represents the firm's total production costs.

It is assumed that the firm produces and uses its own technical knowledge. It does not license its knowledge to other firms and it does not have free access to the knowledge of other firms.

The stock of technical knowledge (A) used by the firm in its current goods production period (t) can be expressed as follows:[1]

$$[6.3] \quad A_t = A_{t-1} + dA_t$$

The expression above states that the technical knowledge available to the firm for use currently is equal to the stock /

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1. Schott's (1978) work on the technical knowledge production function is useful here. Schott's equivalent of [6.3] above also includes a term representing technological obsolescence in the last period, or $-dA_{t-1}$. It is excluded from the model here due to difficulties in empirical measurement.

stock at the beginning of the period (A_{t-1}), plus any additions to the knowledge stock in the current period (dA_t). While A_{t-1} is predetermined in [6.3], it is actually the result of the same process as noted in that equation or: $A_{t-1} = A_{t-2} + dA_{t-1}$.

In addition to its goods production function, the firm faces a knowledge production function, whereby it can generate new technical knowledge. The output of the firm's knowledge production function will be represented in this thesis by the number of inventions (X_t) generated by the firm over a specific time-period (t). Inventions (X_t) are the output of a flow of applied R & D expenditures (R) and the available stock of basic scientific knowledge (B) associated with the industry.[1] Although a small percentage of basic knowledge is produced by firms, we assume here that it is an exogenous variable supplied as a result of the efforts of university or government research teams. If we hold the level of basic knowledge constant for all t then:[2]

$$[6.4] \quad dA_t = X_t = f(B, R_t, R_{t-1}, R_{t-2} \ldots\ldots)$$

As /

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1. As noted in chapter one, the relationship between the growth of basic scientific knowledge and technology has been questioned by a number of economists. A few have suggested that technology tends to build on itself or that the stock of current technical knowledge (A_t) should also be an input in the production function shown. This of course has implications for assumptions concerning diminishing returns.

2. Schott (1978) includes a technical uncertainty parameter γ, into her equivalent of [6.4] so that $X_t = \gamma R_t$. She does not include the input of basic scientific knowledge however. As we pointed out in chapter three, the majority of firms tend to make small incremental changes, subject to very low technical risk. Since patent data, used in this thesis, reflect these sorts of changes, the uncertainty parameter is excluded in [6.4]

As an alternative to [6.4] above, one might specify that the level of R & D expenditure required for an invention of a particular quality depends on the level of basic knowledge available, B or:

$$[6.5] \quad X_t = f[R_t(B),\ R_{t-1}(B_{t-1}),R_{t-2}(B_{t-2})$$

$$\text{with } R'(B) = \partial R/\partial B < 0$$

Here as basic knowledge or technological opportunities increase, technical knowledge production becomes less expensive.

Substituting [6.4] into [6.3] we arrive at:

$$[6.6] \quad A_t = A_{t-1} + f(B,R_t,R_{t-1},R_{t-2}....)$$

Recognising that inventions in the current period are produced by a flow of R & D expenditures over several time periods, a simplifying assumption will be made rendering subsequent analysis easier to handle. It is assumed here that the firm chooses an R & D programme in the current period which produces inventions in the current period and no other period. Thus we are condensing the R & D flow into a single time period.[1] Nordhaus (1969a,p.18) who uses this technique, explains that the assumption means that 'the model is static in a rather special sense'. R & D is conducted immediately with /

1. In theory the choice of time period becomes tautological or valid by definition. If a time period is chosen which is long enough to encompass all R & D expenditure and all the results of such expenditure, then there will in theory be no accumulation of technology over that time period.

with the programme bearing fruit immediately . The static nature of the model prevents the consideration of an accumulation of technology. Stoneman (1983) who also uses this technique, notes that in each time period a firm has to reinvent the technology it had in the previous period. If we make the assumptions described above, then [6.6] becomes [6.7] below:

$$[6.7] \quad A_t = X_t = f(B, R_t)$$

Where with B fixed: (i) $X_t'(R_t) > 0$

(ii) $X_t''(R_t) < 0$

The second condition in [6.7] above states that there are diminishing returns to R & D expenditure in the production of new knowledge or inventions. There are valid reasons for expecting the returns to R & D to diminish. Given a number of production problems to be solved, inventors may address themselves to the easier and least costly first. As the intensity of the R & D effort increases, the more difficult and costlier problems are attacked. Also for a given R & D project, as additional conventional inputs are added to a constant science base (B), diminishing returns to conventional inputs set in.

Another reason for diminishing returns to R & D, explored by both Nordhaus (1969a) and Evenson and Kislev (1976), arises out of the uncertainty of the inventive process. Applied research may be seen as a search process within /

within a distribution of a random variable with inventors choosing independent research projects. As the number of projects increases, the likelihood of a successful invention increases, but at a decreasing rate. Eventually the distribution becomes exhausted and technology stagnates.

As Evenson and Kislev (1976) note, diminishing returns may be checked by new scientific knowledge, which widens the gap between basic knowledge and the current level of technology in practice. New basic knowledge can shift the mean of the distribution mentioned above, or provide new distributions to search. The same authors add that technological exhaustion should be carefully distinguished from obsolescence. On this point it was Schmookler (1966) who argued that the exhaustion of a field's technological opportunities may never be approached. This is because long before diminishing returns to R & D set in, an industry experiences a diminishing demand for its product and hence adjusts its R & D expenditure downwards.

Assuming basic knowledge to be constant, we can illustrate the invention production function in the Cobb-Douglas form below:

$$[6.8] \quad X_t = B\, R_t^{\alpha}$$

Taking the first derivative of the function with respect to the R & D input gives:

$$[6.9] \quad X_t{}'(R_t) = \partial X_t / \partial R_t = \alpha B R_t^{\alpha-1} = \alpha X_t / R_t$$

where $\alpha = \dfrac{\partial X_t}{X_t} \Big/ \dfrac{\partial R_t}{R_t}$ or the elasticity of invention with respect to R & D

Clearly the marginal product of R & D is greater than zero if α is greater than zero. It is also clear from [6.9] that the marginal product is directly related to the elasticity of knowledge with respect to R & D expenditure and inversely related to the R & D input as a proportion of output or inventions. The level of basic scientific knowledge is in addition a positive influence on the marginal productivity of R & D.

The second derivative of the knowledge production function is as follows:

$$[6.10] \qquad X_t''(R_t) = \frac{(\alpha)\ (\alpha-1)(X_t)}{R_t^{\,2}}$$

The requirement that $X''(R_t)$ be less than zero in [6.7] is satisfied in [6.10] above if α , or the elasticity of invention with respect to R & D is less than one and greater than zero. Since under the restrictions of the Cobb-Douglas function elasticity is constant, if diminishing returns set in, they set in immediately.

Another consideration, arising from chapter four (section 4.3) is the possibility of economies of scale in research inputs (R). Since it is assumed that basic knowledge is constant in [6.7], the model restricts R & D to diminishing returns. In reality however, breaking the composite R & D input down into labour and capital, it is not unreasonable to expect some economies in the scale of the research operation, at least up to a point /

point. While the issue is extremely important, the lack of R & D data makes it impossible to pursue empirically. Therefore, the relationship between R & D inputs and inventive outputs is not explored further. The relationship between inventive outputs and the overall size of the firm is also an important issue and will be pursued empirically.

We can now proceed to analyse the firm's decision to produce process and product inventions. The firm's decision to invent in the models presented is separated from its other decisions, for example on investment and advertising. In reality however, the allocation of resources to R & D is a simultaneous decision on the part of the firm, weighed against the costs and benefits of other investment opportunities. It is also assumed in the models below that the firm can accurately predict the costs as well as the future benefits associated with its inventive activity. If this is true then a profit-maximising firm will produce new technical knowledge up to that point where the surplus of expected revenues from invention over expected costs is maximised, both streams discounted to their present value.

6.2 The Firm's Decision to Produce Process Inventions

The benefit of process inventions to the firm is the resulting fall in the firm's costs of production. This increases the firm's profits at any given output and also may be a means of expanding sales through price reductions. The /

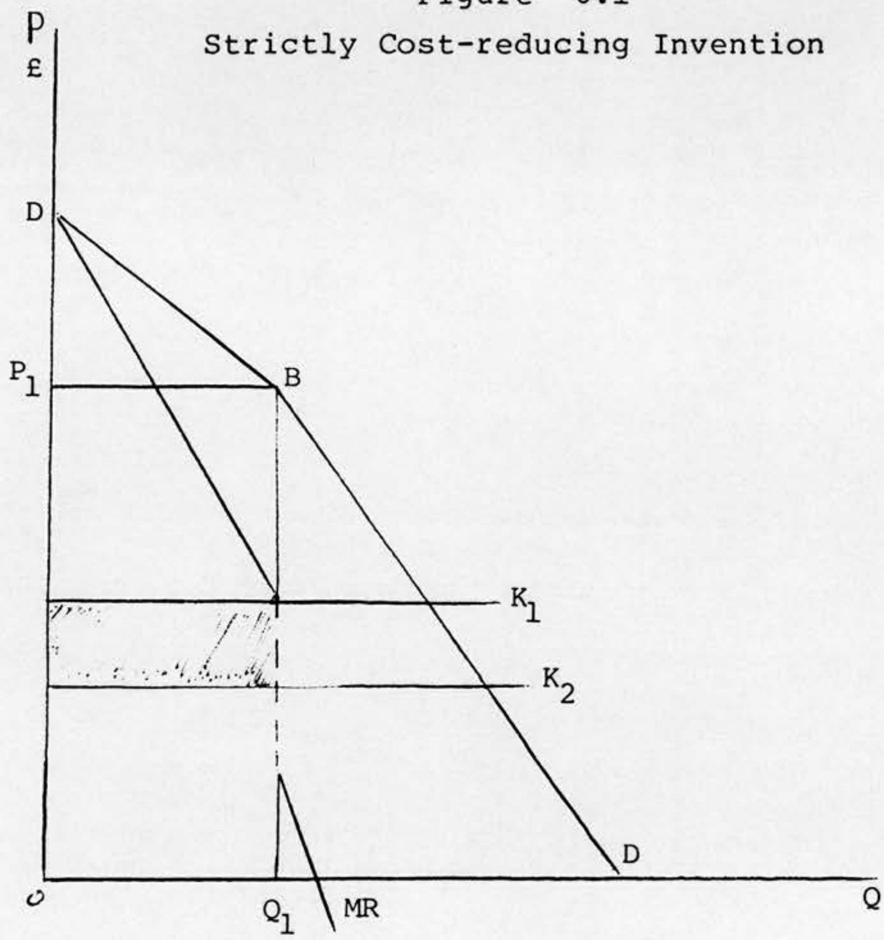
The firm may or may not choose to expand its sales depending on the response of market demand to price reductions and on the response of rival firms in the market.

<u>Strictly cost-reducing inventions</u> In the first model presented, the assumption is that the firm regards its process inventions as strictly cost-reducing. An example of this situation would be a firm in an oligopolistic industry which fears retaliation by rivals if it attempts to drop price in order to expand output. Instantaneous benefits to the firm of inventing and then using the new techniques to lower costs may be seen graphically in figure 6.1. The figure shows the firm's demand curve to be kinked at the current profit maximising point B. If we assume that rival firms immediately match any price reduction, the portion of the demand curve below B (BD) is the firm's constant share-of-the-market curve. This portion of the curve is of course less elastic than that above B(DB), where other firms do not match price changes.

From profit-maximising point B in figure 6.1, the firm invents a new process which lowers its constant unit production costs from k_1 to k_2. Since the new cost curve cuts the firm's marginal revenue curve on its vertical section, the firm maintains its output at Q_1 with price, P_1 after generating its invention. The firm still receives a benefit from its invention in the increased profits from production. This is calculated as the extent of cost-reduction (k_1-k_2) multiplied by the /

Figure 6.1

Strictly Cost-reducing Invention



Increase in profits =

the firm's output level, Q_1. If this gain is greater than the expenditure on R & D required to generate the new invention, the firm will gain a positive net benefit and therefore decide to proceed with the invention.[1]

Figure 6.1 clearly shows that the total benefit derived by a firm from a cost-reducing invention is directly related to firm size. This is simply the 'demand-pull' hypothesis or 'extent of the market' argument discussed in chapter four. If the R & D necessary to generate a given level of cost-reduction is fixed, then the more units over which the cost-reduction is spread, the greater the benefit to the firm. While the effect of firm size on the incentive to produce process inventions is clear from the diagram presented, the relationship of other variables, such as technological opportunity, need examining more closely. In order to do this we proceed to the development of profit maximising models of firm inventive activity.

In the first model presented, as in figure 6.1, it is assumed that the firm faces constant unit production costs (k). Research and development activity (R) may be viewed as resulting in additions to production process knowledge or process patents, or $X_c = f(R)$, which in turn /

1. The statement implies that there are no costs involved in utilising the new technology in the production process. In fact the firm may have to invest in new capital equipment or retrain workers to use its new technique. These costs would also have to be considered in any decision to proceed with an invention.

turn reduce k, or $k = k(X_c)$. The profits associated with cost-reducing inventions are fully appropriable by the firm from t = 0 to t = T, after which they fall to zero. At T the firm's patent on the process expires or the process becomes obsolete. In reality the profits from an invention are not likely to be eliminated so abruptly, with a gradual decline in profits over time more likely. While the firm does not attempt to increase its market share, it s sales may grow or even decline due to an underlying growth or decline in total market demand. We assume here that the growth or decline in market demand occurs at a constant proportionate rate of g.

The net present value to the firm of its process inventions is expressed in [6.11] below:[1]

$$[6.11] \quad V = \int_{t=0}^{T} pQ_i - Q_i k(X_c)\ e^{-(r-g)t}\ dt - R$$

where: V = present value of invention's net benefits

p = price of product

Q_i = output of firm i

k = constant per unit cost of production

X_c = the number of process patents produced in the current period

r = firm's discount rate

g = constant rate of growth or decline in market demand

T = the invention's life

R = expenditure on R & D activity

and where $X_c = f(B,R)$ from [6.7] and:

$r > g$ for convergence

Integrating and rewriting gives:

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1. This model incorporates the features of a number of models including Barzel (1968), Nordhaus (1969a), Kamien and Schwartz (1969) and Needham (1975).

$$[6.12] \quad V = [pQ_i - Q_i k(X_c)] \left[\frac{1-e^{-(r-g)T}}{r-g}\right] - R$$

Setting the discount factor, $\frac{1-e^{-(r-g)T}}{r-g}$ equal to ϕ, the first-order conditions for a profit maximum with respect to R & D is:

$$[6.13] \quad V'(R) = \partial V/\partial R = 0 = -Q_i \; \partial k/\partial X_c \partial X_c/\partial R \; \phi - 1$$

Rearranging and with $k'(R) = -\partial k/\partial R$ we can write:

$$[6.14]^1 \quad 1 = Q_i \; k'(R) \; \phi$$

Equation [6.14] states simply that the value of the marginal product of R & D must be equal to its marginal cost, or in this situation R & D expenditure itself, if profits from invention are to be maximised. The value of the marginal product, as the right-hand-side of [6.14] shows, is the rate of cost reduction k'(R) due to the production of additional knowledge evaluated at the firm's level of output (as in figure 6.1). The result again demonstrates that the rewards from cost-reducing invention are directly related to firm size.

Equation [6.13] shows the role of R & D clearly, as an input which produces another input, process knowledge. From /

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1. The result here is equivalent to that of Kamien and Schwartz (1969, p.673), who view process change as factor-augmenting and close to that of Nordhaus (1969a,p.22).

From [6.13] and [6.9] it can be seen that the amount of new technical knowledge produced depends on B, the level of basic scientific knowledge or technological opportunity. Unsurprisingly, the value of invention varies positively with the invention's life and with the rate of growth of output and inversely with the discount rate, r, and the rate of decline in output (e.g. if $g < 0$).

Equation [6.14] gives a result concerning profit maximisation with respect to R & D expenditure for strictly cost-reducing inventions. The more interesting case however, is where the firm may use its new production technology to expand its output and lower its price. It is from this case that the empirical model of process patenting is developed and to which we now turn.

<u>Expansion of Output with Process Inventions</u> As a result of a cost-reducing invention, a firm, firm i, may be in a good position to lower its price and increase its level of output. The firm will therefore move to a new profit-maximising equilibrium, at a higher output, a lower price, and a lower unit cost, if the increase in profits is greater than the R & D expenditure required to produce the cost-reducing invention.

In an oligopolistic situation however, the level of profits from such a move by firm i depends on the reactions of rival firms. As a result of firm i's invention, other firms in the market may decide to engage in /

in R & D enabling them to match the inventing firm's now lower production costs. If these firms hold back price changes until their new processes are developed, firm i may be able to capture a greater market share while the price differential lasts. Here firm i finds itself on demand curve dd in figure 6.2. As a result of an invention, unit costs are reduced from k_1 to k_2 and price from p_1 to p_2. The increase in profits in this situation is due both to cost-reduction $(K_1 - K_2)$ and expanded output $(Q_2 - Q_1)$, as shown by the shaded areas in the figure.

In the model of process invention developed below, it is assumed that the firm, firm i, maximises profit not only with respect to R & D but simultaneously with respect to output. Cost reductions due to the firm's R & D expenditures therefore affect the firm's equilibrium position with respect to output and price. Using the same terms as in the previous model, the net present value to firm i of output-expanding process invention is expressed below:

$$[6.15] \quad V = \int_{t=o}^{T} p(Q_i)Q_i - k(X_c)Q_i \; e^{-(r-g)t} \, dt - R$$

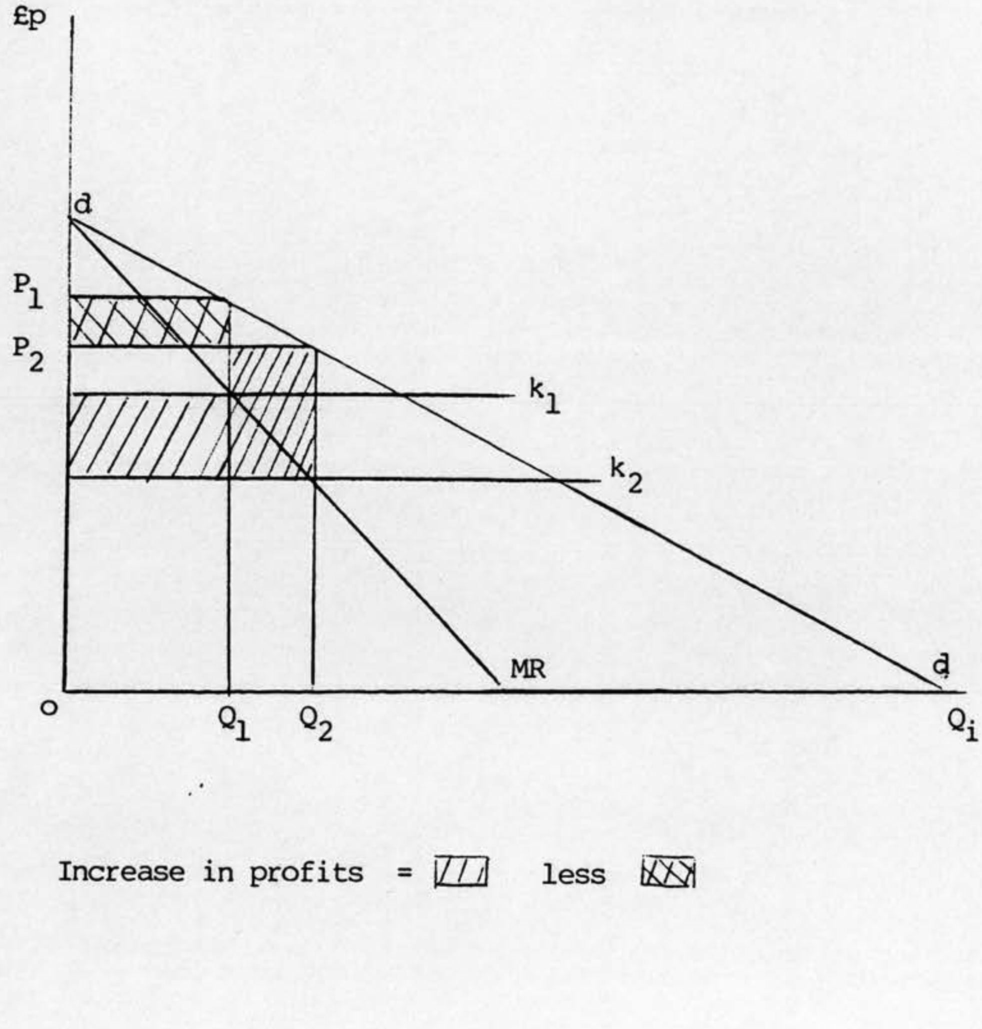
again where: $X_c = f(B,R)$
and $r > g$ for convergence

Integrating, setting the discount factor $\phi = \dfrac{1-e^{-(r-g)T}}{r-g}$; and rewriting gives:

$$[6.16] \quad V = [p(Q_i)Q_i - k(X_c)Q_i] \; \phi \; - \; R$$

First-order conditions for a profit maximum are:

Figure 6.2
Output-Expanding Process Invention



Increase in profits = [hatched area] less [cross-hatched area]

[6.17a] $V'(R) = O = -\partial k/\partial R \; Q_i \; \phi - 1$

[6.17b] $V'(Q) = O = [p + Q_i \partial p/\partial Q_i - k] \; \phi$

Simplifying and rearranging [6.17a] and [6.17b] respectively we have:

[6.18a] $1 = k'(R) \; Q_i \; \phi$, where $k'(R) = -\partial k/\partial R$

[6.18b] $1/n = p-k/p$

where $n = -\partial Q_i/\partial p \; p/Q_i$ or the price elasticity of demand for firm i's product

Equation [6.18a] is exactly the same as the previous first-order condition for the strictly cost-reducing case expressed in [6.14]. On the other hand, equation [6.18b] is the familiar profit-maximising relationship between a firm's price and its marginal cost. Taking equation [6.18a] and multiplying both sides by R and the right hand side by k/k gives:

[6.19] $R = -\partial k/\partial R \; R/k \; Q_i k \; \phi$

Setting $e_k = -\partial k/\partial R \;\; R/k$, the elasticity of unit cost reduction due to R & D expenditure, it follows that:

[6.20] $R = e_k \; Q_i \; k \; \phi$

However, from [6.18b], $k = p(1 - 1/n)$. Therefore substituting for k in [6.20] gives:

[6.21] $R = e_k \; pQ_i(1-1/n) \; \phi$

Expression /

Expression [6.21] shows the optimal level of research when a firm directs R & D expenditure toward reducing costs and expanding output. To arrive at an expression for optimal process patenting, which is more useful for empirical purposes, both sides of [6.21] are multiplied by X_c/R giving:

$$[6.22] \quad X_c = X_c/k(-\partial k/\partial X_c \partial X_c/\partial R)\ pQ_i(1-1/n)\ \phi$$

if $-\partial k/\partial X_c \partial X_c/\partial k\ R/k$ is substituted for e_k in [6.21]

Simplifying, we have:

$$[6.23] \quad X_c = e_{k(x_c)}\ \partial X_c/\partial R\ pQ_i\ (1-1/n)\ \phi$$

where again $e_{k(X_c)}$ represents the elasticity of unit cost reduction with respect to additional process inventions.

Expression [6.23] states that the amount of inventive activity undertaken by a firm is related to: the response of unit production costs to changes in inventive activity; the marginal product of R & D with respect to invention; the level of firm sales; a price elasticity term and the discount factor. The result for optimal invention in [6.23] is very similar to that in [6.21] for optimal research. There is a slight adjustment in the unit cost elasticity definition in [6.23] to allow for inventions rather than research as the independent variable. An added /

added term is the marginal product of R & D ($\partial X_c/\partial R$), showing the number of inventions to also be a dependent variable. The two terms together, as explained previously, represent the technological opportunities available to the firm. The marginal product of R & D is shown in [6.9] to be positively related to a fixed level of basic scientific knowledge. The number of additional patents generated is however not in itself indicative of technological opportunity as the quality of the process patents produced may vary substantially. The elasticity term reflects this quality by showing the responsiveness of production costs to new process knowledge as measured by patents.

As with the previous result for strictly cost-reducing process inventions, inventive activity in the output-expanding model is related to the discount factor $\phi = \frac{1-e^{-(r-g)T}}{r-g}$. There is a positive relationship between the level of invention in a firm and the rate of growth of output and the life of the inventions. The discount rate, r, is negatively related to invention or patenting activity. Unsurprisingly there is also a positive relationship between the level of inventive activity and the level of firm sales.

Equation [6.23] shows the firm's price elasticity of demand to be positively related to its inventive activity. This result is valid for all values of price elasticity greater than one. If price elasticity is equal to or less than one, the firm would not be able to increase /

increase revenues by expanding output and equation [6.23] is not relevant. Instead the strictly cost-reducing case is appropriate.

The positive association between inventive activity and the firm's price elasticity of demand shown in result [6.23] is intuitively appealing. The invention-induced price reduction results in a greater expansion in output for the firm with the more elastic curve. As previously explained, the total reward to the cost-reducing invention increases as it is spread over a greater amount of output.

A number of economists, including Needham (1978) have demonstrated that the firm's price elasticity of demand depends on a number of factors. These include the firm's market share, the price elasticity of total market demand for the firm's product, and the reactions of rival sellers. The price elasticity of the firm's product will be greater the more price elastic is total market demand. If however, the firm expects rival sellers to increase the quantity of output they produce in response to a price reduction by the firm, the firm's demand curve will be steeper than that of the market demand curve. Given the price-elasticity of the market demand and the reaction /

reaction of rival sellers, the lower the firm's share of the market, the greater it's price elasticity of demand.[1] This is because the lower the firm's share of the market, the larger will be the p/Q_i component of the firm's price elasticity of demand. Intuitively the smaller the firm's share of total market demand, the greater the potential for winning some of the larger share held by rival firms.

The relationship between firm and industry price elasticity of demand can be seen more clearly by comparing the result for optimal R & D intensity obtained by Stoneman (1983) with our own result or equation [6.21]. Stoneman makes the Cournot assumption that the decision-making firm does not expect rivals to react to its increase in output as the result of R & D devoted to process changes. The Stoneman (1983, p.34) result, using the terminology of this paper is as follows:

[6.24] /

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1. Needham (1978, p.59) shows the formal relationship between a firm's price-elasticity of demand, its market share, market elasticity of demand, and rivals' reactions in the following expression:

$$E_d = E_m/S_f + E_s S_r/S_f$$

where E_d and E_m represent firm and market price elasticities respectively
S_f and S_r represent the market share of the firm and its rivals respectively and;
E_s represents the elasticity of rival's supply

[6.24] $R/pQ_i = e_k \ (1 - {}^{S}f/n_m)$

where: n_m is the price elasticity of market demand and
S_f represents firm i's market share

The difference between equation [6.21] and [6.24] is in the use of firm price elasticity in [6.21] and industry price elasticity in the Stoneman result. Equating the two expressions, $1/n = S_f/n_m$ or $n = n_m/S_f$. Firm i's price elasticity of demand is equal to market price elasticity divided by firm i's market share when there is no expected reaction on the part of rivals. This is equivalent to the Needham formula for firm price elasticity previously described.

It is useful to note here that firm i's price-cost margin, equal to the reciprocal of its price elasticity of demand, will from the above formula depend on market elasticity and firm i's share of the market. The lower this share,the higher the firm's price elasticity and therefore the lower the optimal excess of price over marginal cost. This infers that the greater the ability of the firm to hold price above marginal cost the lower process patenting intensity.

From the discussion above it can be demonstrated that when there are no reactions on the part of rivals, the firm's price elasticity of demand will decrease continuously with increases in concentration. Higher levels of concentration here imply a higher market share, S_f, /

S_f, for firm i, which may be regarded as the typical firm in the market. Therefore, in this respect, increases in concentration have a strictly negative influence on process patenting intensity. While the assumption concerning rival reactions is plausible at low levels of concentration, as the number of firms decrease,firm's become more interdependent and it is more likely that a price decrease by any one firm will be matched. If this is the case then firm's maintain their market share with price changes and therefore industry price elasticity becomes the firm's price elasticity. Increases in concentration in this situation have no effect on firm price elasticity, and therefore process patenting intensity. It can be predicted therefore that process patenting intensity will decrease as concentration increases up to that point at which price matching becomes normal and thereafter there will be no further decreases in patenting intensity.

6.3 The Firm's Decision to Produce Product Inventions

The distinction between process and product technology is that while the former may affect demand through the price variable, the latter affects demand directly through its quality enhancing characteristics. Therefore any competition/

competition in process technology between firms may be viewed as price competition, while product quality competition may be considered true technological competition.[1]

The benefit of product inventions to the firm is the resulting increase in demand for the firm's products, which in turn increases its profits, market share or its rate of growth of output. Product inventions may open up entirely new markets to the firm with new product introductions. Alternatively product quality improvements may have the effect of increasing the firm's market share at the expense of its rivals. Product quality improvements may also move the industry demand curve out at the expense of other products. Since most inventions, as has been emphasised, fall in the category of minor improvements, we focus on product quality improvements here. However, the analysis is similar to that for new products, since new and improved products replace existing products, just as new improved product characteristics replace existing characteristics.

As with the case for process inventions, the instantaneous benefits to the firm from using its newly produced knowledge to increase product quality can be shown graphically. Assuming constant unit costs of production, figure 6.3 shows the rightward shift in firm i's demand curve, from d_1d_1 to d_2d_2, due to the use of its product-enhancing invention. /

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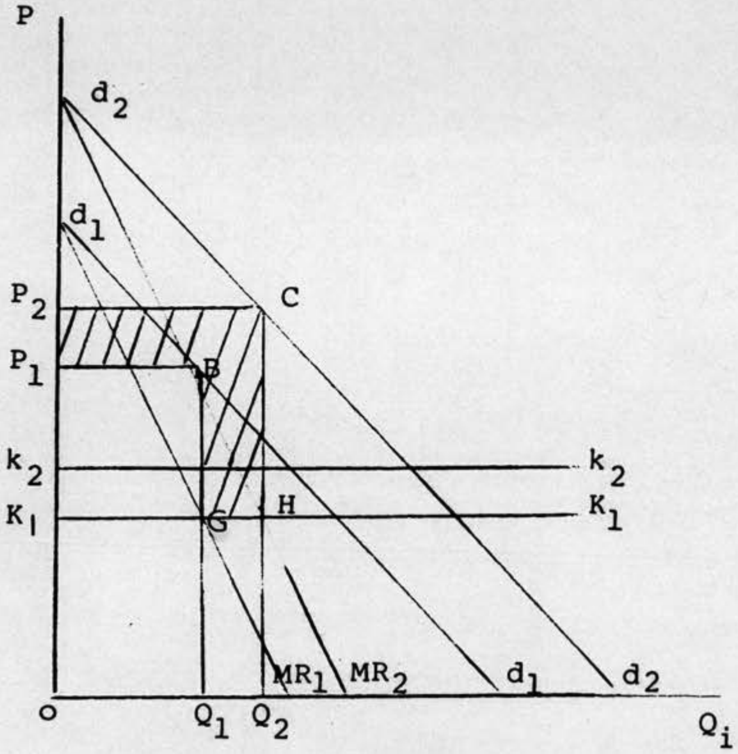
1. This is not strictly correct since improvements in production processes may enhance product quality as well as efficiency.

Figure 6.3
Product-Enhancing Invention



Increase in profits

invention. If we assume no changes in production cost due to the new invention, the firm's profits increase from P_1BGk_1 to P_2CHk_1, or by the shaded area in the figure.

Figure 6.3 shows that increased profits as a result of product invention are due both to an increase in output, Q_2-Q_1 and an increase in the margin between price and average cost, P_2-P_1. As with process patenting, the benefits of product patenting are related to firm size. The graph shows clearly that the more units over which the price increase, resulting from enhanced quality, is spread, the greater the total benefit to the firm.[1]

In the case presented in the figure, the profit-maximising firm would go ahead and invent if the increase in profits due to the invention, or the shaded area in figure 6.3 is greater than the cost of developing and using the invention. It should be pointed out that the assumption has been one of no increase in unit costs of production due to invention. If however unit costs were to increase, for example from k_1 to k_2 in figure 6.2, as a result of the new technology, post-invention output would be reduced and post-invention price increased with the effect of reducing post-invention profit. In the extreme /

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1. Usher (1964, p.282) demonstrates this using indifference analysis. He shows that the inventor of a new product with a patent grant restricts output of his new product so as to create a gap between the marginal rate of substitution in use between the new and old product and the marginal rate of transformation in production. The output of the inventor weighted by the gap between the two prices is the inventor's revenue.

extreme case production costs could be increased to the point of making the product improvement unprofitable. In reality, in such cases the firm may have to develop a new production technology to enable it to offer the improved product at a profit-making price. As in the previous section on process inventions, we turn to the development of the firm-decision-making model for product inventions.

In the model of product patenting below, the firm competes both on the basis of its price (p) and on the basis of its product technology, represented by the number of product-enhancing patents(X_d) produced through the R & D process or $X_d = f(R,B)$. The firm's level of output therefore depends both on its price and its product technology. While this model takes no explicit account of rivals, it should be remembered that the gains to the individual firm from product patenting depend on the reaction of rival firms. Unlike process patenting however, where rivals are immediately able to match price cuts, it is expected that improved products take rivals some time to develop. The firm's unit cost of production (k) is again assumed constant against output. It is also assumed that production costs remain constant with quality changes.[1] Similar to the analysis of process invention we assume an underlying growth or decline /

1. An assumption of a change in production costs due to the product enhancement would make only a small difference to the analysis. As seen from figure 6.3, a production cost increase would reduce the post-invention profits of the inventing firm.

decline in market demand for the firm's products of constant proportionate g; and a life for the firm's invention from t = O to t = T.

Using the same terminology as that used for process patenting the net present value to the firm of its product invention is expressed in [6.25] below:[2]

[6.25] $V = \int_{t=o}^{T} p(Q_i)\ Q_i(X_d) - k\ Q_i(X_d)\quad e^{-(r-g)t}\ dt - R$

where: $X_d = f(B, R)$

$Q'(X_d) = \partial Q/\partial X_d \geq O$

$r > g$ for convergence

Integrating, setting the discount factor, $\dfrac{1-e^{-(r-g)T}}{r-g}$, equal to ϕ and rewriting gives:

[6.26] $V = [p\ (Q_i)\ Q_i(X_d) - k\ Q_i(X_d)]\ \phi\ -\ R$

Maximising V jointly with respect to R&D(R) and output (Q_i) gives:

[6.27a] $\partial V/\partial R = O = \phi\ [p\partial Q_i/\partial X_d\ \partial X_d/\partial R - k\ \partial Q_i/\partial X_d \partial X_d/\partial R] - 1$

[6.27b] $\partial V/\partial Q_i = O = \phi\ [\partial p/\partial Q_i\ Q_i + (p - k)]$

Rearranging, simplifying and dividing both sides of [6.27b] by p gives:

[6.28a] $1 = \phi\ \partial Q_i/\partial R\ (p-k)$

[6.28b] $p-k/p = -\partial p/\partial Q_i\ Q_i/p = 1/n$

where the right side of b is equivalent to the reciprocal of the price elasticity of demand (n) for firm i's product.

Taking /

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2. The model presented here is very much like that of Needham (1975). Needham does not consider the intermediate input of patented technology, only the basic input of R & D.

Taking equation [6.28a] and multiplying both sides by R gives:

$$[6.29] \quad R = [\phi \; \partial Q_i/\partial R \; R] \; (p-k)$$

If the right-hand side of [6.29] is multiplied by Q_i/Q_i and if:

$\partial Q_i/\partial R \; R/Q_i = e_{Q(R)}$ the elasticity of output with respect to R & D devoted to product quality

then:

$$[6.30] \quad R = [\phi \;\; e_{Q(R)} \; Q_i] \quad (p-k)$$

However, from [6.28b], p-k = p/n. Therefore substituting into equation [6.30] gives the following expression for the level of optimal research:

$$[6.31] \quad R = \phi \; e_{Q(R)}/n \; pQ_i$$

Since the data used in this study is patent data rather than R & D data, an expression for patenting activity with respect to product quality is needed. Multiplying both sides of [6.31] by X_d/R gives:

$$[6.32] \quad X_d = \phi \; pQ_i \; X_d/R \; [1/_n \partial Q_i/\partial X_d \partial X_d/\partial R \; R/Q_i]$$

If: $\partial Q_i/\partial X_d \; X_d/Q_i = e_{Q(X_d)}$ the elasticity of output with respect to product enhancing patents

then substituting into [6.32] we arrive at:

$$[6.33] \quad X_d = \phi \; pQ_i \; \partial X_d/\partial R \; (e_{Q(X_d)}/n)$$

Expression /

Expression [6.33] states that the level of the firm's patenting activity is positively related to the marginal product of research and the ratio of two elasticities: the elasticity of output with respect to product patents and the firm's price elasticity of demand. As with the expression developed for process invention, invention concerning product improvements is positively related to the underlying growth in industry demand and the life of the inventions generated and negatively related to the discount rate. Also as with process invention, the level of product invention is positively associated with the level of firm sales ($p\ Q_i$). The influence of the ratio of the two elasticities in both the patenting expression [6.33] and the R & D expression [6.31] is like the ratio of elasticities in the expression for advertising intensity developed by Dorfman and Steiner (1954).[1] Before exploring the significance of the elasticity terms further, the differences between [6.33] and [6.31] the expressions for patenting and R & D activities respectively should be noted.

The results for R & D activity in [6.31] and patenting activity in [6.33] are very similar. In the latter expression, the fact that product technology or patenting is the output of the R & D process which is in turn used as /

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1. Dorfman and Steiner (1954) demonstrate that the profit-maximising firm should set its advertising-sales ratio equal to the ratio of its advertising elasticity of demand to its price elasticity of demand.

as an input in production, must be accounted for. This is accomplished through the additional term in [6.33], the marginal product of R & D or $\partial X_d/\partial R$. Also, demand responds to additional patents in [6.33] or we have $e_{Q(X_d)}$ instead of $e_{Q(R)}$ in [6.31], with demand responding directly to R & D.

As with process patenting the marginal product of R & D represents the technological opportunities available to the firm. The greater the level of basic scientific knowledge, where $X_d = f(B,R)$, the greater the number of patents of a given quality due to any additional R & D expenditure. The elasticity of output with respect to patenting $e_{Q(R)}$, represents the response of consumers to the improved product. The expression therefore reveals something about the quality of the additional product inventions as judged by consumers. Unlike its counter expression $e_{k(X_c)}$ in the process patenting equation [6.23], showing the response of unit costs as a measure of patent quality, $e_{Q(X_d)}$ does not measure product quality directly but only in terms of its value in the market place. In this respect the elasticity term points to the opportunities available for technological competition on the basis of product characteristics. As discussed in chapters four and five, a number of economists have made the distinction between technological opportunity on the supply side and the opportunities for technological competition on the demand side.[1]

Evaluating /

1. See for example Comanor (1967) or Shrieves (1978) or the discussion in section 5.2 of this thesis.

Evaluating the influence of the ratio of the two elasticities $e_{Q(X_d)}/n$ in equation [6.33] in more depth, it is important to recognise that both are relevant to the individual firm and not to the industry as a whole. In the case of a monopoly, the firm and the industry are identical so no distinction is necessary. However, for other market structures, the distinction is important.

First it should be noted that the relationship between the firm's price elasticity and product patenting intensity is negative in [6.33]. while the relationship was positive in the case of process inventions [6.23]. The negative relationship however, becomes intuitively clear when we consider that the inverse of price elasticity of demand (1/n) is equal to the price-cost margin (p-k/p). Therefore the lower firm price elasticity, the higher the price-cost margin and therefore the higher the increase in profits due to an increase in sales as a result of product improvements.

As with process patenting, it is instructive to relate the firm's price elasticity of demand in equation [6.33] to market price elasticity of demand. The firm's price elasticity (as explained in the case of process patents) will be higher, the higher market price elasticity, the lower the firm's market share and the smaller the reaction of /

of rival firms to firm i's price decreases.[1] These three factors are negatively related to product patenting intensity. If we assume no reaction on the part of rivals, concentration, which increases with the market share of typical firm i may be seen to be positively related to product patenting intensity. At some point however, the level of concentration may itself have an effect on rival reactions, therefore complicating its effect on product patenting intensity. The influence of concentration is further complicated by its relationship to $e_{Q(X_d)}$ which is now explored.

The relationship between the responsiveness of demand to product improving inventions $e_{Q(X_d)}$ is obviously positive. It is useful however, to consider any factors that may affect this responsiveness.

An increase in product quality may affect the firm's sales in a number of ways. Total market demand for the product might increase, benefiting the inventing firm. Also, the firm may increase its share of the market at the expense of rivals. If rivals retaliate by engaging in their own R & D to generate product inventions, then the initial inventing firm may not benefit from as large an increase in sales. A possible result however,

is /

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1. This assumes of course that rivals change output in the same direction as the inventing firm, firm i. If rival firms were to decrease their output as a result of an increase in firm i's output this would mean a higher price elasticity for firm i.

is that the rival's new inventions will boost total market demand further. If this is the case, retaliatory action need not be so damaging. Therefore both the market elasticity of demand with respect to product inventions and the reactions of rivals influence $e_{Q(X_d)}$.

Market elasticity of demand with respect to product quality may be related to the type of product produced. If the product is one which can be differentiated with respect to technical characteristics then competition is more likely to be technological rather than on the basis of price.[1] As a number of economists have suggested, durable consumer goods and capital goods generally fall into this category.

It has already been noted that the level of concentration has a positive relationship with product patenting intensity, through the price elasticity relationship. What remains to be explored however, is the relationship between $e_{Q(X_d)}$, demand elasticity with respect to product patenting and market structure.

A number of economists have suggested that technological competition under oligopoly will be particularly intense. It is argued that here firms anxious to avoid price competition, will turn to non-price forms, including technological competition. Also, with increased /

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1. It is possible that a firm might use product quality improvements as a means of lowering its price elasticity and providing an opportunity to increase prices.

increased interdependence, the reaction of rival firms to any product quality changes by an individual firm will be strong. The question is whether this increased interdependence, leads to a higher or lower patenting intensity.

Needham (1975) demonstrates that the expected reaction of rivals can lead to a lower product patenting intensity on the part of the profit-maximising firm.[1] If rivals increase their own R & D as a result of an initial invention from firm i, and thereby generate their own product improvements, firm i's benefit will be lower. The reduction in patenting intensity therefore is due to diminished appropriability of the rewards of patenting.

The prediction above however, needs to be qualified. It is based on the assumption that the decision-making views R & D activity strictly as an offensive strategy for increasing profits. If R & D activity devoted to product/

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1. Needham (1975, p.254) shows that the profit-maximising research intensity of a firm is as follows:

$$R/pQ = \frac{E_R + E_{conj}\, E_{Rr}}{E_d}$$

where E_R and E_{Rr} represent firm i's demand elasticity due to R & D expenditure by the firm itself (R) and its rivals (Rr) respectively. E_{conj} represents conjectural variations concerning rivals R & D and E_d represents firm i's price elasticity.

product improvements is necessary on the part of the firm to protect its profits and/or market share, this must increase the patenting intensity of the firm. In other words firm i would itself react to product changes initiated by other firms. Defensive type of R & D spending on the part of both firms leads to a prisoner's dilemma situation, where both firms fail to maximise profits due to high R & D expenditure.

The arguments considered concerning the relationship of oligopolistic interdependence and patenting intensity may be summarised by referring to Scherer's (1980, p.429) remark concerning the 'clash of structural propensities.' While rivals stimulate R & D spending for defensive reasons, they also discourage invention if due to rival reactions few benefits of the invention are expected to be appropriated.

6.4 The Firm's Decision Concerning Overall Inventive Activity

It is useful both from a theoretical and empirical standpoint to consider the firm's decision to produce inventions overall or both product and process inventions. Here the firm undertakes R & D with the goals of lowering costs through product invention and/or expanding output through product or process invention. The decision-making model in this case becomes a combination of the product and process invention models previously developed.

The net present value to the firm of its total inventions, /

inventions, continuing to use the same terminology, is given in [6.34] below:

$$[6.34]\quad V = \int_{t=o}^{T} p(Q_i)Q_i(X) - k(X)Q_i(X) \quad e^{-(r-g)t}\, dt - R$$

where: $X = X_d + X_c = f(B,R)$

$Q_i{}'(X) = \partial Q/\partial X \geq O$

$k'(X) = \partial k/\partial X \leq O$

$r > g$ for convergence

Again, integrating, setting the discount factor $\frac{1 - e^{-(r-g)T}}{r-g}$, equal to ϕ and rewriting gives:

$$[6.35]\quad V = [p(Q_i)Q_i(X) - k(X)\, Q_i(X)]\ \phi - R$$

Maximising V jointly with respect to R & D (R) and output (Q_i) we have:

$$[6.36a]\quad \partial V/\partial R = O = [p\partial Q_i/\partial R - k\ \partial Q_i/\partial R - Q_i\partial k/\partial R]\ \phi - 1$$

$$[6.36b]\quad \partial V/\partial Q = O = [p + Q_i\ \partial p/\partial Q_i - k]\ \phi$$

Simplifying and rearranging gives the following:

$$[6.37a)\quad 1 = [(p-k)\ \partial Q_i/\partial R\ \phi] - [Q_i\ \partial k/\partial R\ \ \phi]$$

$$[6.37b]\quad 1/n = p-k\ /p$$

Equation [6.37a] is a combination of the first-order conditions for process and product patenting expressed previously in [6.23] and [6.33] respectively. Again, [6.37b] is the familiar expression for the firm's profit-maximising price-cost margin.

Multiplying /

Multiplying both sides of [6.37a] by R gives:

$$[6.38] \quad R = [(p-k)\ \partial Q_i/\partial R\ R\ \phi] - [Q_i \partial k/\partial R\ R\ \phi]$$

If on the right-hand side of expression [6.38], the first bracketed expression is multiplied by Q_i/Q_i and the second by k/k, this leads to:

$$[6.39] \quad R = [(p-k)(Q_i)\ (e_{Q(R)})\ \phi] - [Q_i\ k\ e_{k(R)}\ \phi]$$

Here $e_{Q(R)}$ and $e_{k(R)}$, as before, equal the elasticities of output and cost with respect to research. Substituting from expression [6.37b] for both (p-k) and k in (6.39] gives:

$$(6.40] \quad R = \phi\ pQ_i\ [(e_{Q(R)}/n) + (e_{k(R)}(1-1/n))]$$

As expected, total research activity is simply a combination of the expressions for research devoted to process changes and that devoted to product changes or [6.31] and [6.33] respectively. This result is equivalent to that of Stoneman (1983) although in somewhat different form.[1]

In order to convert research activity into inventive activity, both sides of [6.40] are multiplied by X/R giving:

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1. Stoneman's model incorporates a number of additional features including the possibility of scale economies in the R & D process, technological obsolescence and the output response of rivals to firm i's new process knowledge.

giving:

$$[6.41] \quad X = \phi\, pQ_i\, \partial X/\partial R\, [(e_{Q(X)}/n) + (e_{k(X)}(1-1/n))]$$

The elasticity terms in [6.41] now relates to additional patenting activity rather than R & D directly.

The result in [6.41] shows that total patenting activity varies with the impact of additional patents on either output ($e_{Q(X)}$) or production costs ($e_{K(X)}$). As with the product and process patenting equations, technological opportunity or the productiveness of R & D in generating additional patents is positively associated with total patenting activity. The relationship of price elasticity of demand (n) to total patenting activity however, is indeterminate in [6.41]. Price elasticity has a direct relationship to process patenting activity and an inverse relationship to product patenting activity.

6.5 The Possibility of No Inventive Activity

The discussion up to this point has surrounded the relationship between a number of variables and the level of research or inventive activity. In anticipation of the possibility of obtaining zero values for firm patenting activity in the empirical analysis to follow, it is worth pointing to the theoretical justification for no patents.

From expressions [6.23] and [6.33] for process and product invention respectively, it can be seen that if one /

one of the terms on the right-hand side of the expression is zero, then patenting activity must be zero. Since firm sales is not expected to be zero, the problem must lie with one of the other variables. On the supply side, the reasons for no firm patenting activity could be due to technological opportunities which are nonexistent. The exhaustion of a firm's science base, may mean that the marginal product of R & D ($\partial X/\partial R$) is zero or that the response of unit costs (in [6.23]) or product quality (in [6.33]) is nil. Also, in reality, there may be some risk involved in inventive activity, which when combined with other factors leads to a decision not to invent.

On the other hand, the reason for a decision 'not to invent' might be on the demand side. If for example, in the case of product patenting, price elasticity were close to infinity, or very competitive markets existed, then product invention would tend toward zero. This does not hold for process patenting when price elasticity is close to zero however, as the firm can still increase its profits by cost-reduction as in [6.14]. The empirical difficulties associated with zero values for firm patenting activity are discussed in chapters seven and eight.

6.6 Summary

The models of process, product and total patenting activity developed in this chapter by no means incorporate all of the complexities of the inventive process. Simplifying /

Simplifying assumptions which render the models empirically tractable, also have the effect of reducing realism. The exclusion of such items as technological obsolescence and uncertainty, while justifiable from an empirical standpoint, reduce the comprehensiveness of this theoretical section. Another noticeable feature in the development of the models, is the isolation of inventive decision-making from other aspects of firm decision-making, such as investment. In reality capital investment and investment in knowledge production may compete for funds; or decision-making may be simultaneous.

The chapter, nevertheless, has provided more rigorous justification for the inclusion of particular variables in any empirical analysis of patenting activity. The following chapter discusses the difficulties encountered in measuring or choosing proxies for these variables. The theoretical models also suggest a functional form for estimating the patenting equations. This is also dealt with in the following chapters.

CHAPTER SEVEN

EMPIRICAL MODELS OF PROCESS AND PRODUCT INVENTION

In the previous chapter a number of firm decision-making models were developed with respect to inventive activity. Assuming that the firm seeks to maximise profit from its inventive activity over time, results can be derived showing the optimal number of process, product, and total inventions to be generated by a firm. While the variables affecting optimal inventive activity follow logically from the theoretical decision-making models, many are not directly measureable. In this chapter therefore, the equations for optimal invention are developed into directly testable forms.

The two basic equations which shall be referred to in this chapter are the previous [6.23] for process invention and [6.33] for product invention. These shall be re-numbered as [7.1] and [7.2] respectively as shown below. The total patenting equation [6.41], renumbered here as [7.3] is comprised of the same terms as are either in the process or product equation.

[7.1] $X_c = (pQ_i)\ (\partial X_c/\partial R)\ (e_k)\ (1-1/n)(\phi)$

[7.2] $X_d = (pQ_i)\ (\partial X_d/\partial R)\ (e_Q/n)(\phi)$

[7.3] $X = (pQ_i)(\partial X/\partial R)\ [e_Q/n + (e_k\ (1-1/n))](\phi)$

The /

The terminology used remains unchanged from the previous chapter, with a small exception. The elasticities e_Q and e_k represent the response of output and unit production cost respectively to invention as opposed to R & D. Since R & D is not considered directly here, the subscript (X) denoting invention in the last chapter is dropped.

Prior to discussing the measurement of the variables in equation [7.1], [7.2], and [7.3], it is useful to address the functional form which the estimating equations should take. Since the expressions in the equations enter multiplicatively, this implies that the empirical tests should be conducted in logarithmic form. Transforming the process patenting equation [7.1] gives:

$$[7.1a] \quad \log X_c = \log pQ_i + \log(\partial X_c/\partial R) + \log e_k + \log(1-1/n) + \log[1-e^{-(r-g)T}] - \log(r-g)$$

where $\frac{1-e^{-(r-g)T}}{r-g}$ has been substituted for the discount factor ϕ.

If we assume that the firm's inventions have an infinite life, or T is equal to infinity, then $[\log[1-e^{-(r-g)T}]$ is equal to zero provided r is always greater than g. While this assumption is obviously unrealistic, it is a convenient method of reducing the equation to a simpler form. Also, data on the life of inventions for different firms and industries is not available, /

available, so T, at least must be assumed constant across industries.[1] Making the T = infinity assumption, [7.1a] becomes [7.1b] below:

[7.1b] $\log X_c = \log pQ_i + \log(\partial X_c/\partial R) + \log e_k + \log(1-1/n) - \log(r-g)$

If the same steps are taken in transferring [7.2] and [7.3] to logarithmic form, this gives:

[7.2b] $\log X_d = \log pQ_i + \log(\partial X_d/\partial R) + \log e_Q - \log n - \log(r-g)$

[7.3b] $\log X = \log pQ_i + \log(\partial X/\partial R) + \log[e_Q/n + (e_k(1-1/n))] - \log(r-g)$

The procedure in this chapter will be to discuss the measurement of the variables in the two equations, [7.1b] and [7.2b]. Because many of these variables cannot be directly measured, proxy variables must in some cases be developed for use in their place. While this adds to the difficulty in interpreting results and in the precise determination of a functional form, it cannot be avoided in a study of this nature.

The variables discussed are in some cases measured at the firm-level and other cases at the industry-level. In the instance of industry-level variables, the proper classification of a firm into an industrial category is very /

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1. Schott (1976) provides data on the lifespan of innovations from her survey of applied R & D in the largest U.K. firms. The lifespans are broken down by durable and non-durable goods however, which amounts to the same type of distinction used in our industrial class dummy variable explained in Section 7.4.

very important and not always an easy task. This aspect of the study is stressed later when the empirical results are analysed. The sales variable is discussed first, because it is on this basis that firms were selected for the study.

7.1 The Sales Variable ($p Q_i$)

In order to test equations [7.1] and [7.2], the largest manufacturing firms in the UK were selected from The Times Top 1000 1972/73. This annual publication ranks the largest firms in the country by turnover in the proceeding years. While chapter eight, which follows, discusses the rationale for the selection of firms for the study and the characteristics of those firms, here the emphasis is on the sales variable itself.

The initial firm sales variable used in the study is turnover in 1971.[1] This year is important in that a number of other variables are defined so as to be consistent in terms of time period. Regression equations are also tested however using sales values for 1972, 1973 and 1974, which are taken from subsequent years of The Times Top 1000 publication. Due to the time-consuming task of tabulating patent data for more than one time period, any lag period between the sales and patent data is fixed by altering the year for the sales figure.

The /

1. Sales data is reported by firms for either the year ending January 1972 or the year ending March 1972 in The Times Top 1000 1972/73.

The year 1971 was chosen for the initial sales variable to provide a four year lag of patenting activity on sales (patents are counted from 1975). The assumption here is that sales is a demand variable providing a stimulus to inventive activity. Patents are generated however only some time after the initial stimulus to account for research and development time and for the official processing of patent applications. The lag of four years is on average consistent with information concerning the length of R & D projects and the period of time lapsed between patent application and acceptance and publication.

A survey of the largest 300 U.K. firms by Schott (1976) shows that the majority of applied R & D projects undertaken in industry are short-term in nature. Sixty per cent of the projects successfully completed were finished in two years or less with only eleven per cent requiring four years or more, (Schott, 1976, p.85-86). The results of the survey support the hypothesis that most industrial R & D is dedicated to relatively minor advances.

Information from Taylor and Silbertson (1973, p.13) reveals that there is a one and one-half to two and one half year lag between patent application and acceptance by The Patent Office. If the two time periods, the R & D period and the acceptance lag, are combined, this results in a four and one-half year lag between the initial demand stimulus and /

and resulting patented inventions. The patent data, described in the following section are taken from a fourteen month period from late 1974 to early 1976. The 1971 figure for sales therefore provides approximately the correct lag, considering the information available.

The four year lag of patenting on sales or the demand variable, chosen for the initial estimates of patenting activity in this study, is generally equal to or greater than those used in similar studies concerning patenting or R & D activity. Stoneman (1979) for example, in his U.K. industry-level study of patenting activity, tests a number of lag periods and also Koyck transformations. He reports that the results from his use of a simple one-period lag 'indicate the flavour of all the results generated' (Stoneman, 1979, p.39). And while Scherer's (1965a) earlier firm-level study of patenting activity in the largest U.S. firms provided for a four year lag of patenting on sales, in his later industry-level study (Scherer, 1982) his best results are obtained with patents lagging demand-pull variables by only two years. Scherer explains that these results are either due to chance or a tendency for corporate inventors to anticipate favourable demand conditions even before they fully materialise.

Pavitt and Soete (1980, p.48) have gone so far to suggest that due to the very nature of patenting activity, 'the search for time-lags is unnecessary and could even be misleading.' The view here is of patenting activity undertaken /

undertaken to protect innovations over the entire life-cycle. The pattern is one in which a major innovation results in a master patent and following that a cluster of improvement patents.

Further information is provided by Hall, Griliches and Hausman (1984) in a recent study concerning both the patenting and R & D behaviour of 642 US firms. In attempting to characterize the lag structure of the patents to R & D relationship, the authors find a strong contemporaneous relationship between R & D expenditures and patenting. The relationship does not disappear when firm size is controlled for.

Considering the discussion above a fixed four year lag for patenting on the sales variable can be questioned. To account for possible variations in time lags in this study therefore, sales values for the three years following 1971 are substituted into the regression equations and results compared.

7.2 The Measurement of Inventive Activity (X) or Number of Patents

Inventive activity in this thesis is measured by the number of patents registered by a firm in The Patent Office of the Department of Trade and Industry over a given period of time. As explained earlier, the use of patent data suits the purposes of the study, in both a theoretical and a practical sense.[1] The discussion below describes the step by step procedure undertaken to arrive at the number /

1. See chapter one, section 1.4 for a justification of the use of patent data.

number of product patents and process patents for a firm. All of the patent data used in this thesis was compiled from U.K. Patent Office publications available in the Edinburgh Central Library.

A total number of patents was first assigned to each firm with reference to the Index of Patentees. This lists the names of firms and individuals applying for patents in alphabetical order, and for each name the patent specification numbers (six figure serial numbers) of all specifications accepted by the patent office in the time period covered by the particular volume of the index. Although accepted by the patent office, the patent is only sealed after a period of time in which it may be challenged. It is reported by Boehm (1967, p.76) that 96 per cent of U.K. patent acceptances are sealed.

In compiling patent data for the firms used in this thesis, two volumes of the Index of Patentees were referred to.[1] This resulted in a count of patents for each firm over a period of fourteen and one half months covering all of 1975. A patent count over a longer period of time would have been preferable in order to average out any short-term fluctuations. Mueller (1966), for example has suggested a three to five year period for cross-sectional analysis. However, because /

1. The first volume refer to patent specifications 1375001 to 1400000 published between 27 November 1974 and 2 July 1975. The second volume refer to patent specifications 1400001 to 1425000 published between 9 July 1975 and 11 February 1976.

because of the intent to separate the firm's product patents from its process patents, any longer period of time would have required a prohibatory amount of work.

As a crude test of the consistency and reliability of the patent data over a short period of time, the number of patents assigned to a firm from the first volume of the Index of Patentees was correlated with the number of patents assigned to a firm from the second volume of the index. The resulting correlation coefficient was .967. This implies a stable pattern of patenting activity on the part of firms over this short period of time.

A particular problem faced in assigning a total patent count to a firm is the separate listing of a firm's subsidiaries in the Index of Patentees. The names listed are those of the patent applicant. If a parent company applies for a patent on its own behalf or the behalf of a subsidiary, the name of the parent will be listed. However, if a subsidiary applies for a patent on its own behalf, only the name of the subsidiary is listed.[1]

In order to accurately assign patents to the parent firms selected for the study, a knowledge of the subsidiaries of each parent company was required. To obtain this information the 1971 U.K. edition of

Who /

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1. This was confirmed in a letter from The Patent Office to the author - Judith Sullivan, Examiner, Classification Section, The Patent Office to Ms P A Siler, 30 July 1981.

Who Owns Whom was consulted.[1] The 1971 volume was selected because it is consistent with the volume of The Times Top 1000 from which the firms used in the study were taken. The patent specifications for each of the firm's subsidiaries were then added to those listed under the parent's name to arrive at a total count for the parent company.[2]

It should be recognised that some inconsistency can arise from using a 1971 ownership structure for firms to assign patents in 1975. For example, if a parent firm sold major subsidiaries with significant patenting activity during the period the patent count would not reflect the existing ownership of the firm. If however, the four year lag discussed in section 7.1 is valid, or patents abridged in 1975 are influenced by 1971 demand variables, the procedure followed is theoretically sound. Whether or not they are still owned by the parent, patents produced by subsidiaries should reflect demand variables at that time when they were under the relevant parent or in 1971.

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1. A benefit derived from the Who Owns Whom search was the classification of parent firms in the publication into general industrial categories. This was of use in assigning values to each firm for a number of industry level variables used in the study.

2. The pattern of patent application varied widely. In the case of some firms almost all of the patents were applied for under the parent's name (Unilever is an example). In the case of others, patent applications were divided among the parent and major subsidiaries (GEC, for example).

An empirical problem in identifying these demand-led patents arises however, if the patenting policy of the firm changes with ownership. For example, the patents of the subsidiary may be registered under the new owner's name.

It should be noted that while demand variables for years other than 1971 are tested, e.g. sales, 1972, 1973 and 1974, the 1971 ownership structure is retained for assigning patents. To the extent that there were major changes in ownership during these years, the patent count less accurately reflects demand variables in these years.

After a total patent count had been assigned to a firm, patents were separated into those concerning the firm's products and those concerning the firm's processes. This was a time consuming activity. For those firms with under 100 patents registered, all of the patent specifications were checked and the patents classified into either the product, process or unidentified category. For firms with over 100 patents registered, one-half of the patent specifications were checked.[1] The proportion of product or process patents for those checked was then applied to the firm's total number of patents to arrive at a total figure for each category.

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1. There were nine firms in this category: ICI, Unilever GEC, Ford UK, Dunlop, Lucas, Phillips, Plessey and STC.

In order to classify patents, reference had to be made to the patent abidgements themselves. The procedure of the patent office under pre-1977 legislation, relevant to this study, was for the examiner to prepare an abridgement summarising the disclosure of information contained in the patent specification.[1] At the same time the patent specification and its abridgement were classified under one or more units of a classification key. The classification system used by the patent office, as Boehm (1967) noted, is based on the technical content of the specification and has no relationship to the Standard Industrial Classification which is based on products and materials of which products are made.
The classification key used by The Patent Office is provided in Appendix 7.2A. The abridgements for a particular period of time are published in 25 volumes, each covering one or more of the 40 divisions of the classification key. A Divisional Allotment Index to Abridgements lists the divisions under which each six figure patent specification number falls.

For the majority of patent specifications, the separation of product and process inventions was time consuming /

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1. Legislation in 1977 requires the applicant to provide an abstract identifying the technical subject of the invention, replacing the old-style abridgement. Information on the facilities and procedures of the UK Patent Office is contained in the publication, Patents A Source of Technical Information, published by The Patent Office, 1979.

consuming but not exceedingly difficult. The patent abridgement often makes the division quite clear. For example, it is obvious from the patent abridgement describing tobacco feeding - 'tobacco fed to a cigarette-making machine' - that this is a process invention for the applicant, British American Tobacco (BAT). On the other hand the abridgement describing smoking articles - 'filter cigarettes product' clearly refers to a product-enhancing invention for BAT.[1]

In a few cases, where the patent abridgement refers both to product changes and production process changes, both a product and process invention was recorded for the firm.[2] Often such a patent specification and abridgement are classified under two quite different divisions in the classification key. An example is the abridgement for a Rank Hovis McDougal patent concerning the improvement of the cold water solubility of gelatin. The abridgement is found in the 'food preparation' category (division A_2) and is counted as a product patent in this study. However, the specification is also counted as a process patent here because it is further classified to the division for 'physical and chemical apparatus and processes' (B_2). The abridgement in this division describes the characteristics of

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1. Abridgements for patent specifications 1397847 and 1378145 are referred to.

2. The double counting of a specification implies that two separate specifications should have been assigned because two inventive steps were involved - one for the product and one for the process.

'a spray gun for spraying aqueous gelatin solutions'.[1] The counting of a specification twice, once as a product invention and once as a process invention is an exception to the general procedure.

For a number of patents, the distinction between a product and process invention required information beyond that contained in the abridgement. This was particularly true of patents of engineering firms, where the apparatus described in an abridgement could either refer to a product sold by the firm or be used in the firm's own production process. In such cases, if the equipment described was a product of the firm, the patent specification was classified as a product invention. An example is the case of Dunlop Ltd., which has a number of patent specifications referring to conveyor belts. Since this is an industrial product of Dunlop, the specifications are classified as product inventions.

A number of sources were used to gain information concerning the products sold by firms. The Annual Cards provided by Extel Statistical Services Ltd., giving company profiles compiled from annual reports were particularly useful for this purpose. In a number of cases the company annual reports were also referred to. In addition the publication Kompass - 10th edition and the /

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1. The particular patent specification discussed, 1411751, is assigned to three divisional units, the two listed in the text above, and a third, C_3, macromolecular compounds. The applicant was Heiner and Sons, a subsidiary of RHM Ltd.

the Department of Trade and Industry's Directory of Businesses from the 1968 Census of Production also provided information on the products of particular firms.

Unfortunately, but not unexpectedly, there were a number of patent specifications where the distinction between a process and product invention could not be made. In these cases the patents were classified as 'unidentified'. In a few situations the patented invention did not correspond to any of the products sold by the firm or fit into the firm's production process.[1] The greater problem was in classifying a patent which was both specific to the firm's production process and which was related to products sold by the firm. For example, the patents registered by British Oxygen Company (BOC) are difficult in this latter respect, due to the nature of the firm's sales. The company sells industrial gases but also plant and equipment for the separation of gases. In a patent related to the liquefaction of hydrogen, accepted from BOC, the invention could be concerned with the firm's own production process or oriented toward the market for its plant and equipment sales.[2] While the invention might serve both purposes; to classify it to both process and product categories implies two inventive steps, which it is not. The patent therefore is classified as unidentified. /

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1. An example is a patent (1408203) registered by BAT concerning a printed circuit card. This patent did not fit into any product line or production process of either the parent company or its subsidiaries under the time period covered.

2. Patent specification 1408203 is referred to here.

unidentified.

Patents were hard to classify for a number of firms in the chemical industry.[1] Besides the volume of patents registered by Imperial Chemical Industries (ICI), the separation of product and process patents was made more difficult by the scientific descriptions of chemical compounds and processes in the abridgements. Despite this however, the abridgements do give clues as to the proper assignment. For example they describe 'mixing methods' or 'devices for circulating liquids' or 'a process for continuous production' which imply an improved process of production. Also, the divisions to which the patent specifications are assigned are helpful. If a specification is assigned to a mechanical as well as a chemical division, it is likely that there is a new physical production process involved. However despite these clues, the product-process distinction was more difficult for chemicals than other industries.

A particular problem in dealing with general chemical firms such as ICI was with patents relating to catalysts. These could be used in chemical production processes within ICI or sold to customers. The 1972 Annual Report for ICI reported for example, that a current R & D project was the development of car exhaust catalysts for use by car /

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1. This was not true of all firms within the chemical industry however. Firms manufacturing pharmaceuticals registered patents which were relatively easy to classify.

car manufacturers. Unless a catalyst invention was specifically related to a product or process in the abridgement, it was classified as an unidentified patent.

While the breakdown of product and process patents for individual firms and industries in this study is discussed in the next chapter, it is useful here to provide some check on the accuracy of the classification procedures used. This is done by considering the average proportion of 'identified' firm patents which are classified as product or process. For all of the firms in the study, 68 per cent of patenting activity on average was undertaken to improve products. This majority is consistent with all other studies referring to the product-process breakdown.

It is also useful to compare the 32 per cent process patenting figure with the findings of Schott (1976) who conducted a survey of allied R & D expenditure among the largest U.K. firms. Schott's survey showed that 37 per cent of R & D expenditure went toward process innovations, (Schott, 1976, p.85). The author notes that this figure is higher than the fifteen per cent figure generally assumed and based on earlier U.S. surveys.

A plausible hypothesis is that the percentage of R & D devoted to process inventions should be higher than the percentage of process patenting. This is because firms have a greater financial interest in and therefore a greater propensity to patent products which are highly visible /

visible to competitors than processes which may be easier to keep secret. If this is correct, the average product patenting percentage using our data is roughly in line with Schott's findings, but significantly lower than the U.S. estimates.

There is no doubt that the procedures used to classify patents to product and process categories are not error-free. It is also true that, had more resources been available to devote to the activity, both in terms of time and expertise; more confidence could be placed in the results. However, given that patents are an index rather than a precise quantification of inventive activity and given that most patents were relatively easy to classify, the procedures followed here should give results which reflect the breakdown of inventive activity directed at products and processes. Appendix 7.2B gives examples of firm patent specifications which have been classified as product, process and 'unidentified' inventions.

7.3 Technological Opportunity $(\partial X/\partial R)\ (e_k)(e_Q)$

Technological opportunity, from chapter four on the theory of invention, may be defined as the advance in the underlying basic scientific knowledge associated with an industry. In this sense it represents the supply side of the inventive process. The higher the technological opportunities, the lower the cost of producing an invention of a particular quality.

As explained in the previous chapter, technological opportunity /

opportunity is associated in equations [7.1] and [7.3] with the marginal product of R & D ($\partial X/\partial R$) weighted by the quality of inventions generated. This quality is shown by e_k for cost-reducing inventions and e_Q for product-enhancing inventions. As noted in chapter six, because there is no direct measure of product quality increases in our model, the response of demand, e_Q, is used. However, this term goes beyond the supply notion of opportunities somewhat to indicate the opportunities for technological competition.

The technological opportunities available to a firm are not directly measurable due to a lack of data. While information on patented inventions exists, neither R & D expenditure nor the number of R & D employees are available at the firm level. Therefore neither the marginal nor average product of R & D activity can be calculated. The lack of firm-level data in itself however, is not bothersome, as the advance in underlying basic scientific knowledge is defined as an industry-wide variable. A possibility therefore, is to use the industry technological opportunity variable developed by Stoneman (1979) in his U.K. study.

Stoneman represents the differences in industry technological opportunities by R & D expenditure per patent produced. He argues that industries with extensive opportunities would have lower R & D costs per patent than those with limited opportunities. In the terminology of this thesis, the Stoneman index is the /

the reciprocal of the average product of R & D expenditure. It is constructed, using the patent data converted by Boehm into an industrial classification scheme. Applying government published R & D data, Stoneman derives two sets of observations on R & D expenditure per patent, one for 1956 and one for 1959, both of which cover fourteen industries.

There are a number of problems in using the Stoneman index to represent technological opportunity in this study. One such problem is that Boehm's industrial classification of patents stops at 1960. This would mean that the technological index used would be somewhat old considering the mid-1970's patent data used here. Another potential problem is that the industry break-down used by Stoneman may be too broad. This is due to R & D expenditure data being available only for some industries only at the industrial order level of the SIC. However within a general industrial classification, such as textiles, there may be some subclasses, such as man-made fibres with substantially higher technological opportunities. The general category of electrical and engineering also contains firms in the electronics subcategories, which are likely to have had greater opportunities in the 1970's than other firms in the general category. It is preferable therefore to adopt a technological opportunity measure from data which has greater potential for a break-down by industrial subclasses.

In this study the technological opportunities available /

available to a firm will be measured by a proxy variable. This is the density of qualified scientists and engineers (QSE's) employed in the major industry in which the firm is engaged. Information on QSE's in industry is obtained from the Census of Population. Data from the 1971 Census will be used here because it reflects the technological opportunities available at that time when the firm, according to our theory, is initiating projects generating patent specifications in 1975-76. The Department of Industry derives its industry tables on QSE's by processing a 10 per cent sample of census forms for Great Britain for persons aged 18 or over and falling within the Department's definition of a QSE.

The Department of Industry defines a qualified scientist or engineer as a person holding a first qualification at degree level or above in engineering, technology or science. QSE's are published by industry of employment and by subject area under the general categories of science, technology and engineering.[1] Data is available at the three digit SIC level. The figures for density of QSE's by industry are obtained by dividing the QSE values by the number of employees in the particular industry in 1971, published by the Department of Employment,[2] and /

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1. Department of Industry, Persons with Qualifications in Engineering, Technology and Science, Studies in Technological Manpower No. 5 (London: HSMO, 1976). Table 1, pp.43-49.

2. Department of Employment, British Labour Statistics Yearbook, 1971, (London: HSMO, 1973), table 57, pp.132-139.

and then multiplying the result by 100. This gives the number of QSE's per 100 employees in the industry or the density figure used in this study.

As noted previously, there may be some question as to how widely or narrowly the industry technological opportunity variable should be defined. In this study the QSE variable is measured and entered into the regression equations at both the three digit SIC level and at a broader industrial order level. The broader definition does however have subclasses for electronics and aerospace, two industries where the science and engineering base is stronger than that of the industrial order as a whole. Appendix 7.3 contains a table showing the density of QSE's by broad industrial orders broken down by scientists and engineers and technologists. A potential problem with the wider industry measurement is the association between the QSE variable and industrial class dummy which is explained in the following section.

It may be argued that the number of scientists, engineers and technologists employed within an industry merely reflects the demand for inventive inputs and therefore cannot be used as the supply variable, technological opportunity. Bosworth (1981) however, makes the point that qualified scientists and engineers within a firm are involved in a much wider range of activities than R & D. These activities include production, installation and testing of new capital equipment /

equipment, advertising and marketing. While the QSE figure for an industry may therefore partially depend on the demand for inventive inputs in an industry, it also reflects the extent to which an industry is science-based. It is assumed here that the greater the density of QSE's in an industry, or the more QSE's per 100 industry employees, the greater the science base of the industry, or the greater the technological opportunities available.

A further consideration is whether the total figure for both qualified scientists and engineers should be used in calculating the technological opportunity proxy. If we return to the original concept of technological opportunity, it is regarded as the exogenous advance in science which opens up new opportunities for applied research.[1] In this case the use of qualified scientists alone in deriving the industry technological opportunity variable seems justified.

A number of economists however, have asserted that technology may not be closely related to science but subject to laws of its own. This would imply that the appropriate measure of the 'cumulative technological base' of an industry would be measured by the density of engineers alone. A more complex view, that of Nelson and Winter (1982), distinguishes between industries with 'cumulative technologies' and those with 'science-based' technologies. Fortunately /

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1. See the theoretical discussion of technological opportunity in Chapter 4, section 4.2.

Fortunately the QSE data allows us to separate the density of scientists from the density of engineers and technologists in an industry to accommodate the theoretical differences concerning the concept of technological opportunity.

Each firm in our sample of the largest firms in the U.K. is assigned several technological opportunity variables for use in the empirical tests of the patenting activity equations. The technological opportunity variables assigned depend on the industry into which the firm is classified. The classification of a firm into an industry therefore is again stressed as a very important feature in the study. The initial industrial classification of a firm is by major product. The major product however, in the case of a number of diversified firms may not accurately reflect the technological opportunities available to the firm in its other industries. Therefore a second technological opportunity measure is used which is the density of QSE's in the highest density QSE industry which the firm supplies.

Another variable which may reflect the technological opportunities available for production process changes is the degree of productivity already achieved in the industry. This approach to technological opportunity may be traced back to the theory of the product cycle and its relationship to technological change explained in section 4.8. The theory suggests that in the latter stages /

stages of the product cycle, when production processes become highly capital intensive and productivity is high, the opportunities for production process changes may be diminished.[1] Nordhaus (1969) used this method, predicting the level of industry productivity to be negatively associated with the number of inventions generated in an industry.

As an alternative technological opportunity variable in estimating patenting activity, an industry productivity variable is used. The same prediction is made as that by Nordhaus above; that the productivity level has a negative influence on patenting activity.[2] The productivity level used is output-per-operative in the major industry in which the firm operates. Output-per-operative figures were obtained for three and four digit SIC levels from the Census of Production (1971).[3] The firm's major industry, used in assigning the productivity level variable, is the same as that used to assign the QSE variable.

7.4 Price and Product Quality Elasticity of Demand (n), (e_q)

The response of demand to both a change in the firm's price/

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1. This neglects the possibility of a completely new production technology, perhaps with a different science base, being adopted.

2. It should be noted that Waterson and Lopez (1983) make the opposite assumption; that technological opportunity and capital intensity are positively related.

3. These figures were taken from Wood (1976), who compares productivity among U.K. industries.

price and a change in its product quality are important determinants of patenting activity. In equation [7.1] the firm's incentive to generate process patents is positively related to its price elasticity of demand. On the other hand, product patenting in equation [7.2] is directly related to the elasticity of demand with respect to inventions generating product quality improvements and negatively related to the price elasticity of demand.

Unfortunately, for the purposes of this study, neither of the elasticity variables are directly measurable. While some data has been generated on the price elasticity of demand for particular products, the data is by no means comprehensive over the wide range of industries represented here. The measurement of the response of demand to product quality improvements has been attempted in only a few studies using hedonic price indices (see for example Cowling and Rayner, 1967). Considering these restraints, a proxy variable must be developed to represent both types of elasticity in this study.

The proxy variable used to represent both price and product quality elasticities faced by the firm is the firm's industrial type. Two general industrial categories are defined for the purposes of this variable: (1) those in which products are differentiated and sold on the basis of their performance characteristics; and (2) those in which products are homogenous, being sold largely on the basis of price. The former are industries which /

which primarily sell either capital goods or consumer durable goods. The latter are industries which sell primarily either material inputs or consumer non-durables.

The firms selected for this study are categorised into either the durable or nondurable types described above on the basis of their industrial classification in The Stock Exchange Official Yearbook 1971. A list of industrial classifications is provided in appendix 7.4. The yearbook is useful for our purposes because it groups industries into the more general categories of capital goods, consumer durables and consumer nondurables. Although building material industries are classified as capital goods in the yearbook, the industries are reclassified for this study into the non-durable material inputs category.[1] Firms not having a stock exchange listing in 1971 were classified into an industry type on the basis of their major products. Information concerning the major products of firms was obtained from The Times Top 1000 and also the publication Kompass, which lists the SIC numbers into which a company's products have been classified.

The firm's basic industrial type is entered as a dummy variable in estimating both product and process patenting activity. Taking the process patenting equation [7.1] first, the assumption made here is that firms in the nondurables category (building materials and consumer nondurables) have relatively high price elasticities. This /

1. A few industries in the 'other' category in the stock exchange listing were also reclassified for our study-drugs and chemicals to non-durables and office equipment to durables.

This in turn has a positive influence on their process patenting activity. As explained in chapter six, this is because for any fall in price due to cost-reducing invention, firms with higher price elasticities are able to spread the benefits of the invention over a greater number of units, other things equal. On the other hand, it is assumed that firms in the durable goods category (either capital goods or consumer durables), have a relatively low price elasticity and a relatively high elasticity with respect to product quality.

The proxy variable developed here is only in the broadest sense representative of the various elasticities firms actually face. However, a variable distinguishing industry type seems necessary, especially in estimating the product patenting equation. As explained in chapter four, firms in industries in which products are highly differentiated are more likely to engage in technological competition.

7.5 Industry Concentration

A further influence on the elasticity terms (n) and (e_Q) in equations [7.1] and [7.2] is the level of industry concentration. As explained in the previous chapter,if rival reactions are negligible,the level of industry concentration should have a negative effect on price elasticity and a positive effect on product quality elasticity of demand. It follows therefore, from /

from the equations, that concentration should be negatively related to process patenting activity and positively related to product patenting activity.

As explained in Chapter Six however, the predictions above may be too simplistic, when the relationship between concentration and rival reactions is considered. For example, it was demonstrated that if, after a certain level of concentration, a price decrease on the part of one firm was matched by rivals, then further increases in concentration would have no effect on firm price elasticity and therefore process patenting. For product patenting intensity it was explained that in oligopoly situations, expected reactions of rivals could reduce the appropriability of an invention and therefore the propensity to patent for the firm.

From the discussion above, it is evident that it is difficult to predict a clear role for a concentration variable in estimating [7.1] and [7.2]. However despite this unclarity, a measure of industry concentration is entered in both the process and product patenting equations. The measure used is the five-firm concentration ratio in terms of output of the firm's major industry. Figures are taken from the 1970 Census of Production.[1]

7.6 The Industry Growth Rate, g

The /

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1. See: Department of Industry, Business Monitor C 154, 1970 Report on the Census of Production Summary Tables, London: HMSO, 1976, Table 9, pp.110-197.

The underlying increase in industry output, g, is positively related to both process patenting intensity and product patenting intensity, due to its inclusion in the discount factor $\phi\ (1-\frac{e^{-(r-g)T}}{r-g})$. Industrial growth rates are calculated from yearly sales figures available at the three-four digit SIC level from the Census of Production. Here we use the 1968-72 average compound rate of growth for the firm's major industry.

7.7 Summary

The discussion in chapter seven can be summarized by reviewing the variables to be used in testing equations [7.1] through [7.3]. They are as follows:

Inventive Activity		X_c, X_d, the number of process and product patents registered by a firm over a 14 and 1/2 month period covering 1975.
Sales or Firm Size		Firm sales for 1971, 1972, 1973 or 1974, depending on the lag used for patenting on sales
Technological Opportunity		The density of qualified scientists and engineers in the firm's major industry (QSE) or the level of output-per-operative (QperOp) in the firm's major industry.[1]
Price and Product Elasticities of Demand	(1)	The type of industry (Stxclass) in which the firm produces, either consumer durables and capital goods or consumer nondurables and intermediate goods.
	(2)	The five-firm concentration ratio (Conc) in the firm's major industry
Industry Growth Rate		The average compound rate of growth, 1968-1972 (I Growth) of the firm's major industry.

1. For Sources, see Business Statistics Office (1977, 1972).

While equations [7.1] and [7.2] for process and product invention are to some extent distinct in form, the variables used in their empirical estimation are the same. A number of variables - sales, technological opportunity and industrial growth - enter the two equations in the same way, so it is not surprising that there is some similarity. However, due to the unavoidable use of proxy variables to measure such factors as price and product quality elasticity of demand, the two equations are estimated using all of the same variables.

The influence of the variables may differ however, depending on whether product of process inventions are being considered. For example, while industry type (Stxclass) is used as a proxy for both elasticity variables, the type most favourable to either product or process invention differs. The influence of industrial concentration also changes, although the influence of this variable on both product and process patenting is complex.

Following the logarithmic form specified in [7.1b] and [7.2b], the empirical estimating equation for both product and process patenting is:

$$\log X = a + b_1 \log \text{Sales} + b_2 \log \text{QSE} + b_3 \text{Stxclass} + b_4 \log \text{Conc} + b_5 \log \text{Growth}$$

It should be noted that the interest rate has been dropped from equations [7.1b] and [7.2b], under the assumption that they are equivalent for all firms. The estimation of the /

the total patenting equation [7.3b] also follows the form above.

A potential problem in estimating the product and processing equations is that a number of the independent variables may be interdependent. For example firm size or sales may be directly related to the level of concentration in an industry, depending on the overall market size. Also, given that the technological opportunity (QSE) and technological competition (Stxclass) variables are difficult to separate in theory, they may also be related empirically. These and other problems of estimation are taken up in chapter eight where the results of the empirical tests are reported.

CHAPTER EIGHT

EMPIRICAL TESTS OF FIRM PATENTING ACTIVITY

In this chapter the firm-decision making models concerning patenting activity, developed in Chapters six and seven, are examined empirically. Results of the estimates of the product, process and total patenting models are reported, analysed and where relevant compared with those of previous studies. The equations were tested using data applicable to the largest 180 manufacturing firms in the UK based on 1971 sales. The multiplicative form indicated by the theoretical models leads to the use of ordinary least square (OLS) methods of estimation on logarithmic transformations of the variables. A number of general econometric texts were consulted in this respect. The books by Kmenta (1971) and Pindyck and Rubinfeld (1981) were especially helpful.

To better interpret the regression results, it is useful to consider in a bit more detail the firms selected for the tests. In the first section of the chapter therefore, the distribution of the firms in the study by industry type is presented, with the characteristics of each industry type emphasised. In the next section the problems encountered in estimating the patenting activity equations are discussed. Highlighted here is the problem presented by firms which have no patenting activity or the problem of zero values in the dependent variable. The implications for the OLS estimates are explained.

The /

The next three sections of the chapter, sections three, four and five, present the results of the regression concerning product, process and total patenting activity. The results are evaluated and related to the theoretical models of inventive activity. A sixth section considers the explanatory value of the models developed in this thesis, while a seventh section presents regression results broken down by industrial class. In a final section of the chapter an overview of the empirical work is offered.

8.1 Characteristics of Firms Included

Selection Process The models developed for firm inventive decision-making in chapters 6 and 7 were tested on the largest 180 manufacturing firms in the UK. The firms are listed in order of size in appendix 8.1. Also listed is the breakdown of product and process patents for each firm and the general industrial category (Stxclass) in which the firm was placed for purposes of the study. There are a number of reasons for the choice of firms, which are briefly outlined below.

A first justification is related to the applicability of the theoretical model to different size classes of firms. The inventive decision process developed in chapter six is a formal one; the firm considering both the expected costs of invention in terms of R & D expenditure and expected benefits, in terms of demand factors. The patent or product of the inventive process is therefore the result of a decision to consciously undertake R & D.

As /

As noted in chapter two (tables 2.4a and 2.4b), R & D expenditure and employment are highly concentrated in a few large firms in the UK. It is therefore these large firms whose decision-making process is most likely to fit our regression models. The patenting activity of small and even medium-sized firms, where inventions may be the by-product of the production process, is less likely to be relevant here.

A further justification for considering firms in the largest size class is by virtue of their share of inventions and innovations. As pointed out in chapter two, while smaller firms contribute more to innovation than their formal R & D expenditures would suggest, it is still true that firms in the largest size classes introduce the majority of innovations (table 2.4c). As far as invention is concerned, the patents registered by the 180 largest manufacturing firms, used in this study, represent approximately 44 per cent of all patents accepted from U.K. applicants in the time period covered.[1] Considering that a number of very large firms primarily engaged in extraction (e.g. B.P.) with considerable patenting activity are excluded, the figure points to a high level of concentration in patenting activity, although not as high as that in R & D.

A /

1. Over a 14½ month period from 27 November 1974 to 11 February 1976, the selected 180 firms had 4885 total patents accepted by the Patent Office. According to the 93rd report of the Controller General of Patents, Designs and Trademarks, patent acceptances by all UK applicants numbered 9120 in 1975. If this annual total is prorated over a 14½ month period, the firms in our sample would have contributed 44%.

A practical reason for not testing our inventive decision-making models on a sample of firms of all sizes is that most firms undertake no patenting activity at all. A preliminary test of patenting activity among firms of different size classes showed that the majority of firms in seven different industry groupings registered zero patents over the time period covered in our study.[1] Even among the top 180 firms selected for the study, twenty-eight had no patents accepted by the Patent Office. The number of firms with zero patents rises slightly as we move out of the top twenty firms in terms of size and then is steady until the final twenty firms when the number increases considerably.[2] Of the largest 20 firms only one (Allied Breweries) failed to register a single patent over our 14½ month time period. However, eight of the smallest twenty firms selected failed to register patents. The increasing number of firms which would have had zero values as smaller firms were included was one reason for limiting the number of firms to 180.[3]

The /

1. A random sample of ten firms was taken from each of seven industry groups and a patent count conducted. The majority of firms in each group (7 to 8 out of 10) had no patents registered over a period of a year and a half.

2. The distribution of the twenty-eight firms with zero patents is presented in table 8.2 in section 8.2 of this chapter.

3. Another related reason is the considerable amount of work involved in checking parent and subsidiary firms for patent specifications even when values are zero.

The 180 firms used in the study were selected on the basis of their turnover in 1971 as reported in The Times Top 1000, 1972/73[1]. It should be emphasised that the firms included are only those whose primary activity was manufacturing in that year. Since a patented invention by definition applies to 'a manner of new manufacturing', it was felt that firms selected for the tests should at least be primarily engaged in this general activity. As noted above, as a result, some of the largest firms in the U.K., such as those engaged primarily in extraction activities, are not represented in the study.

The study does include firms which are U.K. subsidiaries of foreign parents, such as Ford U.K. In fact a few such firms are among the largest generators of patents in the sample. Phillips, the Dutch controlled electronics firm, with 553 patents is second only to ICI in terms of total patenting activity. Regression equations are estimated with and without foreign subsidiaries and the results compared. A plausible hypothesis is that firms with foreign parents might have propensities to patent which differ substantially from domestic firms.

Profile /

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1. Firms which were among the largest 180 firms in 1971, but which were taken-over by other firms between that year and 1975, the year of the patent count were excluded from the study.

Profile of Firms in the Study It is useful before going to the regression results to look briefly at the industrial structure of the 180 manufacturing firms included in the study. Table 8.1a shows the distribution of the firms according to their general stock exchange classification, from the Stock Exchange Yearbook 1971.[1] Also shown is the industrial distribution in each of three size classes of firms.

It is clear from table 8.1a that the greatest percentage of firms in the study are in the capital goods category followed by firms manufacturing consumer nondurables. Perhaps the most interesting comparison coming from the table is the complete reversal in the relationship between size class and the relative frequency of capital goods firms and size class and the relative frequency of consumer nondurable goods firms. For the largest 50 firms, the greatest numbers are found in the consumer nondurables category.[2]

The relative frequency of the consumer nondurables category decreases as firms get smaller. Capital goods firms, on the other hand, do not dominate the largest 50 firms as they do the other two size categories. The table also shows consumer durable and chemical firms to have a fairly /

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1. Firms which were not listed on the U.K. Stock Exchange were assigned to a category based upon their major products.

2. The table underlines a fact pointed out in a number of studies, for example George and Ward (1975, p.55). This is the dominance of U.K.companies in the food, drink and tobacco sectors (all nondurables) among the largest companies in Europe.

TABLE 8.1a

Distribution of Firms
General STX Class[a] and by Size Class
(in Percentages)

	All Firms	Largest 50 Firms	Inter-mediate 50 Firms	Smallest 80 Firms
pital Goods	38%	20%	42%	46%
nsumer Durables	17	20	17	14
nsumer Nondurables	26	43	23	17
ilding Materials	9	6	8	11
emicals	11	10	10	12
TOTALS[b]	100	100	100	100

he Stock Exchange Yearbook (STX) classification scheme is used with o exceptions. Building materials are classified under capital goods the Yearbook, while in the table above they are a separate class. so a small number of office equipment firms under 'other groups' in e Yearbook are under capital goods in the table.

ercentages may not add to 100 due to rounding.

fairly consistent representation throught the size categories. It should be pointed out that amongst the consumer durable firms are a number of electrical and electronics giants, such as Thorn, Phillips and Plessey.

It is also worth noting that although the largest manufacturing firms in the U.K. have been chosen for this study, even among these firms there is a good deal of variation in size. Sales turnover in 1971 for firms in the study ranged from £1.85 billion (BAT) to £32.0 million (CIBA-Geigy U.K.). The range of total patenting activity varies from ICI at 622 to twenty-eight firms with no patents registered. Both the sales and total patent distributions are skewed to the right, with the patent distribution having the longer right tail. While the mean value for 1971 sales among the 180 firms was £167 million, median sales were £71 million. The average total patent value was about 27, while the median value was 7.

Sales values, patent values and those associated with a number of other variables used in the regression equations also differ considerably depending on the firm's industry type. Again, using the Stock Exchange's general categories, table 8.1b shows the mean values of a number of the variables used in the regression equations by industry. The table shows that firms in the consumer durable and chemical industries have the highest average patenting activity, considerably above the mean for all firms. While capital goods firms register on,average,patents slightly /

TABLE 8.1b

Mean Values of Firm Variables by General STX Category[a]

	All Firms	Capital Goods Firms	Consumer Durable Firms	Consumer Nondurable Firms	Building Products Firms	Chemical Firms
Mean Total Patents[b]	26.8	20.7	59.0	9.2	7.3	55.1
Mean Product Patents	22.3	18.4	49.6	6.4	5.3	44.9
Mean Process Patents	3.5	1.8	7.8	2.6	2.0	6.2
Mean Unidentified Patents	.9	.4	1.6	.2	.0	4.0
Mean Sales, 1971 (£000)	166,557	107,987	184,271	272,367	85,182	160,859
Mean QSE[c]	2.2	2.2	2.1	.99	1.2	5.5
Mean Qperop[d]	2,991	2,498	2,496	3,332	3,304	4,396
Mean Concentration Ratio[e]	.51	.47	.53	.55	.42	.57
Mean Industry Growth Rate[f]	.09	.08	.12	.08	.12	.11
Number of Firms	180	68	30	46	16	20

[a] The Stock Exchange Yearbook (STX) classification scheme is used for classifying firms to industrial categories. See table 8.1a, note a for details.

[b] Mean total patents may not exactly equal the sum of the three subcategories due to rounding.

[c] QSE represents the industrial technological opportunity variable assigned to the firm, the density (per 100) of qualified scientists and engineers employed in its major 3-digit industrial class.

[d] Qperop represents an alternative technological opportunity variable, the output per operative employee in the firm's major 3-digit industry.

[e] The concentration ratio use is the five-firm concentration ratio of the firm's major 3-digit industry.

[f] The industry growth rate is the 1968-1972 average compound rate of growth for the firm's major 3-digit industry.

slightly below the mean value for all firms, consumer nondurable firms and building products fall well below the mean.

While table 8.1b presents the means of absolute patent values by industrial class, it is also useful to look at patenting intensity or the patent to sales ratio. Mean values for patenting intensity are shown in table 8.1c along with means for the percentage of total patents which are product patents and the percentage of total patents which are unidentified. When patenting intensity is considered capital goods firms, along with both chemicals and consumer durables are above the average for all firms.

The low level of patenting activity in consumer nondurable firms is predictable. These very large firms, as confirmed by their high sales value, produce standardised products (tobacco, food products and drink) with little opportunity for product changes. The group has the lowest QSE value of any of the industry categories and the higher than average productivity value (Qperop) is consistent with highly standardised volume production (see table 8.1b).

The very high level of patenting activity for consumer durable firms is less predictable if based on previous findings. This industrial category is dominated in terms of numbers by motor vehicle and components manufacturers who represent 17 of the 29 firms in /

TABLE 8.1c

Patenting Characteristics by Industrial Class

	All Firms	Capital Goods Firms	Consumer Durable Firms	Consumer Nondurable Firms	Building Products Firms	Chemical Firms
Mean $\frac{\text{Patent}}{\text{Sales}}$ [a]	.17	.22	.26	.04	.10	.27
Mean $\frac{\text{Product Patents}}{\text{Total Patents}}$	.68	.78	.76	.45	.58	.82
Mean $\frac{\text{Unidentified}}{\text{Total}}$ [b]	.01	.01	.02	.00	.00	.02

[a] The patent to sales ratio represents total patents per £ 1 million of sales

[b] Unidentified patents are those which cannot be classified as product or process patents. (See section 7.2 for a discussion).

in the group. The firms in these two subcategories register average total patents of 56.4, which is significantly above the average for all firms.[1] In terms of patenting intensity, motor vehicles has a patent per £ million sales ratio of .249 which as seen from table 8.1c is above average for all firms. This high level of patenting activity for the motor vehicles industry contradicts the findings of another U.K. study.

Taylor and Silberston (1973) contrast a relatively high R & D/output ratio in U.K. motor vehicles with a relatively low patent/output ratio. They (Taylor and Silberston, 1973, p.62) suggest, in reference to motor vehicles, that 'these industries are not in general highly "patent conscious" in the way that many branches of the chemical and engineering industries are.' They add that one explanation for the low level of patenting in vehicles is the industry's orientation toward design rather than technological modifications.

The results presented here point to the opposite conclusions as far as patenting activity in motor vehicles is concerned. Far from being mere design modifications, an examination of the patents registered by these firms shows considerable activity in improving vehicle braking systems /

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1. Joseph Lucas, the motor vehicles components manufacturer is one of the largest generators of patents, with 476, among the 180 firms. The consumer electronics firms bring the overall average in the general consumer durables category up to an even higher level of patenting activity.

systems, engines, batteries, indicator switches, gearing systems, etc. Based on this review of patent abridgement, the industry seems to exemplify that theory of technological change described as 'cumulative synthesis,' or continuous small adjustment (see for example, Parker, 1974, p.20). This view is supported by Jones (1983) in his article on technology in the automobile industry. Jones argues that modern automobile design is becoming much more dependent on the results of innovative activity.

An explanation for the inconsistency between the two studies as concerns motor vehicles, lies in the methods used to classify patents to their industry of origin. In this study patents are identified by the firm registering them and then the firm is placed in an industrial category based on its major products in terms of sales. Taylor and Silberston use the industry level data developed by Boehm (1967) to calculate their patent/output ratio for motor vehicles. Boehm didn't deal with the individual firm, but instead placed patents into industries based on their classification in the patent abridgement volumes. As he himself noted, this could be misleading because the patent classification scheme, based on technical content, is not at all compatible with the standard industrial classification scheme.[1]

It /

1. A review of patents accepted from motor vehicle firms shows that this is particularly true in this industry. Many patents fall into the 'electric circuit elements' and 'electric power elements' categories of the patent classification scheme rather than the transport category. Therefore patents attributed to the electrical engineering industry according to the Boehm scheme would in this analysis be attributed to motor vehicles.

It should be emphasised that while contradictory to other evidence, the high level of patenting activity in consumer durables is consistent with a theoretical point developed in chapters six and seven. Because of the nature of their products, it is expected that durable goods firms will base their competitive strategy on technological competition thus leading to a high level of product patents. On the other hand, firms within this general category have approximately the same science base or technological opportunities (QSE) as all firms taken together, (see table 8.1b). These characteristics point to the two dimensions of a firm's technological environment: (1) the richness of opportunity resulting from exogenous advances in science; and (2) the ease with which product characteristics can be changed (see section 7.2).

The chemicals group predictably has a very high level of average patenting activity. It also has by far the highest average technological opportunity level. Table 8.1b however, points to some inconsistencies in the relationship between chemicals and other industries which make chemical firms difficult to classify with respect to our regression equations (see section 7.4). The chemical firms fit generally into the nondurable or intermediate goods industrial category where the products tend to be homogenous and sold on the basis of price. The very high productivity level (Qperop) for the chemical industries is consistent with their high volume production techniques. With chemicals however, products /

products can be easily changed by 'manipulating molecules', leading to a high degree of product change.[1]

The high level of product patenting done by the chemical firms in relation to that of other industries is seen in table 8.1c, which shows the average ratio of product patents to total patents of firms in different industries. This high ratio is consistent with the findings of Mansfield et al. (1977) who found a much greater role for large chemical firms in product than process innovation (see section 5.3). Given that chemical firms have the highest average ratio of product patents of all industrial categories, their placement in an industrial category representing standardised products is questionable. Table 8.1b shows also that chemical firms have on average the highest number of patents which could not be classified as either a product or process patent. In a number of respects therefore, chemicals present difficulties for the study. This means that results including these firms have to be treated with caution.

From table 8.1c it is also clear that capital goods firms have an above average ratio of product patents to total patents as compared to all firms. This is expected, since these firms sell new product technology which can have the effect of reducing costs for purchasing firms. /

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1. The patent abridgements describe many of the inventions of the chemical firms as 'novel compounds'.

firms. Although they exhibit a high level of technological competition, capital goods firms are about average in terms of existing technological opportunities or QSE density (table 8.1b).

Firms in the building products industries - bricks, cement, glass, etc. - resemble consumer nondurables in their below average patenting activity, below average QSE values and higher than average productivity levels (table 8.1b). Firms in this industrial class are on average smaller than consumer nondurable firms and therefore have a slightly higher patenting intensity ratio (table 8.1c).

8.2 Estimation Difficulties

Errors in Measuring the Dependent Variable It must be recognised that errors are likely to exist in measuring the dependent variable or inventive activity in the models developed, if patent numbers are used as an index of invention. This is especially true of the breakdown of product versus process patents where, as noted in section 7.2, a number of patents had to be classified as 'unidentifiable'. There are also likly to be some errors in measuring overall inventive activity. For example, for firms having a large number of subsidiaries, it is likely that some patents were not traced and attributed to the parent firm. Also a firm which has successfully invented may not apply for a patent on the invention. The firm may decide that a patent is not necessary to protect its invention or it may decide that among many imitating competitors, a patent is not worthwhile. A patent count can also overvalue inventive activity in a firm, depending on the quality of the inventions patented. For example, a firm might engage in profuse patenting of minute inventive steps which, using a count of patents, overstates its inventive activity. Recognising the existence of these measurement errors, it must be asked how they affect the properties of the estimated regression parameters.

The effect of a measurement error in the dependent variable can be evaluated by the addition of the error to each side of the estimating equation for inventive activity as in the expression below:[1]

Log /

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1. The analysis here follows the Pindyck and Rubinfeld (1981, p.176) discussion of 'errors in variables'.

$$\text{Log Patent}^* = \beta_1 \text{logSales} + \beta_2 \text{log QSE} + \beta_3 \text{Stxclass} + \beta_4 \text{logGrowth} + \beta_5 \text{logConc} + \log_{\varepsilon i} + \log_{\mu i}$$

Here the variable Patent^* is obtained in a measurement process and may not be the exact number of patents accepted from the firm or:

$$\text{Patent}^* = (\text{Patent})\ \mu i$$

where μi is the measurement error.

If the measurement error in the multiplicative model does not have a mean of one or a log of zero, then the estimating equation needs an intercept term. Intercept terms are provided in the estimated regressions in this study.[1] As long as the measurement error and the independent variables in the regression are uncorrelated however, the estimated regression parameters will be unbiased and consistent. The presence of the measurement error does increase the estimated residual variance, which reduces the significance of the estimated parameters.

An important question for the estimated regressions in this study is whether or not the measurement error associated with total patenting activity is correlated with an independent variable. As noted in section 1.4 of this thesis, a number of economists have argued that the propensity to patent may be inversely correlated with firm size. If this /

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1. Pindyck and Rubinfeld (1981, p.140) note that econometricians do not usually consider the assumption that an error term has a zero expected value. This is because if it has a nonzero expected value, the estimated regression slope parameters remain unchanged while the intercept picks up the effect of the nonzero expected value.

this is the case, the influence of sales on firm inventive activity would be underestimated by the patent measure. Also, in a recent study, Hall, Griliches and Hausman (1984) argue that the patents variable is such that it is subject to relative imprecision at small values.[1] As long as these small patent values are randomly distributed among firms however, this type of imprecision is not overly troublesome to the estimates. The possibility that firms having zero values may be concentrated among smaller firms is discussed in the next subsection.

The measurement error in total patenting activity may also be correlated with independent variables in the equation other than size variable. For example, a likely hypothesis is that firms which are in more concentrated industries will have a lower propensity to patent. Firms in this situation may use their market power rather than the property right provided by a patent to protect their inventions. The measurement error here would lead to some downward bias in the estimated concentration parameter.

There unfortunately is little to be done in this study to overcome the possible bias of the measurement error. Hopefully, the errors are too small and random to destroy the validity of the estimated parameters. Caution however, should be exercised in interpreting the parameters, with the possibility of measurement bias in mind.

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1. The authors find that even among 642 US firms with high research intensity, 20 percent of the firms did not apply for patents in 1976 and more than half applied for less than five (see Hall, Griliches and Hausman, 1984, p.7)

The likelihood of measurement error in the product and process patenting counts for firms is greater than that for total patenting numbers. This is due of course to a classification procedure which is subject to human error. It is to be expected therefore that the residual variance will be greater in these regressions where the patents are broken down into products and processes, leading to lower significance levels than in the total patenting regressions. There is also some reason to predict that measurement errors will be greater in particular industries, such as chemicals, where the largest number of 'unidentified' patents are found. To the extent that this is true, the error terms may be correlated with the industry level variables, giving bias to the estimates of these variables in the regression. In this case the direction of the bias is not easy to predict or to accommodate. It should be stressed again that patent values are not intended to measure inventive activity directly but to provide an index of its volume. Hopefully the size of the errors in measurement is not so great to render even cautious interpretation of results meaningless.

Zero Values for Patenting Activity In the discussion of the theoretical model in chapter six, it was pointed out that zero patenting activity on the part of the firm may be consistent with profit maximising inventive activity. For example, the absence of technological opportunities might lead the firm to a decision not to undertake R & D. More realistically very low technological opportunities combined with /

with some technical risk might mean that R & D effort results in no patentable inventions. It should be restated that while our theoretical model in its multiplicative form does not allow for the possibility of negative patenting activity, alternative approaches might lead to this phenomena. For example a stock adjustment type of model might lead to the firm allowing its current stock of knowledge to become obsolete without replacement. Besides the theoretical rationale mentioned, there are empirical reasons why a zero patent count might be observed. As explained in the last subsection, errors in measurement of inventive activity, using the patent index is a likely cause.

The observance of zero values is particularly a problem in estimating the models of patenting activity developed, as they imply the multiplicative or logarithmic form. As Scherer (1965b) has argued, the test on size is not valid when in logarithmic equations firms having no patents are dropped. This is because if there is any tendency for the smaller firms in the distribution to undertake no patenting activity, this may result in underestimating the influence of firm size. In order to evaluate the difficulties presented by zero values in this study, first the magnitude of the problem and then its implications are addressed.

Table 8.2 shows the total number of firms having zero process, product and total patents and also the distribution of these firms by firm size.

Table 8.2

Distribution of Firms with Zero Patent Values by Size

	Zero Total Patents	Zero Product Patents	Zero Process Patents
Top twenty firms	1	2	2
21 - 40	2	2	6
41 - 60	3	4	7
61 - 80	4	5	11
81 - 100	3	4	9
101 - 120	2	2	12
121 - 140	2	4	9
141 - 160	3	4	16
Smallest twenty firms	8	8	19
Total	28	35	91

It can be seen that 28 firms 15.6 percent of all firms in the study had no patents accepted by The Patent Office in the time period covered. About nineteen percent of firms in the study, or 35 registered no product patents and just over half of the firms in the study, 91, registered no process patents. The much higher number of firms registering no process patents is to be expected considering that firms may have an option of purchasing new process technology embodied in their capital goods. Also there may be less incentive for firms to patent in-house process inventions which may be easier to conceal from competit ors than product inventions. On the other hand, firms may choose to obtain either product or process knowledge by licensing rather than by investing their own resources in R & D.

The presence of zero values in the dependent variable is not unique to studies of patenting activity and R & D. In fact models where the dependent variable is truncated with a lower limit of zero are quite common and estimating techniques have been put forth to accommodate them.[1] In our models, while the dependent variables are not truncated, in transforming patenting activity to logarithmic form, the cases with a zero patent count are excluded from the estimation. The possibility of bias in the simple least square regression parameters therefore, due to the exclusion of the 'zero-value' cases, must be explored. The case is somewhat /

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1. Here the reference is to the familiar Tobit analysis.

somewhat similar to that outlined by Killingsworth (1983), concerning estimation of the labour supply function using a sample limited to workers. The question here, as in the labour supply example, is whether simple regression estimates will suffer from sample selection bias. To answer this question, some indication of the selection bias is needed, along with a judgement as to whether it is substantial enough to be worth worrying about.

Using Killingsworth's (1983) method of evaluating the problem the sample selection rule imposed by the multiplicative or logarithmic form of the estimating equation can be considered.[1] The selection rule of course is that patenting activity be above zero in value. Using only one independent variable, sales, for simplicity and because it was important to the selection of the 180 firms as a whole, the estimating equation may be seen in terms of expected values as follows:

$$E[\log \text{Patent}/\log\text{Sales}] = E[\beta_o + \beta_1 \log\text{Sales} + \log \varepsilon/\log\text{Sales}, \text{ with Patents} > 0].$$

It can be pointed out from the expression above, that the E [$\log\varepsilon$/logSales] will only be equal to zero if the criteria for sample selection (patents $>$ 0) is uncorrelated with the error term, $\log \varepsilon$. However by excluding firms with no patenting activity, some observations with negative error terms /

1. See chapter 3 of Killingsworth for a discussion of selection bias.

terms (leading to patenting activity of zero) will be excluded from the regression. The error terms for those observations remaining in the sample will tend to be positive and correlated with the selection criteria. In this case the error term is not a mean-zero random variable and this leads to biased estimates. In other words simple linear regression methods lead to drawing a line through the middle of a scatter of points without the points with negative error terms and on the horizontal axis being included. If these observations tend to be clustered, for example, in a particular size range, this leads to bias.

It should be stressed that the 180 firms included in the study were selected on the basis of an explanatory variable, firm size, and not on the basis of the dependent variable. Due to the multiplicative or logarithmic form chosen, which excludes firms with no patenting activity, and the fact that firms with no patents are more heavily distributed at the lower end of the size distribution, the question of downward bias in the estimated sales parameter arises.

If the bias discussed in the previous paragraph exists, then it is expected that, within the sample of positive patent value firms, the error term will be negatively correlated with sales. As sales increase a firm can have a negative value error term, still have patents above zero and therefore still be included in the sample analyzed. In this sense the sample has not been selected exogenously, but /

but on the basis of a variable (sales) which is correlated with the error term.

As the firms in the study are in sequence in terms of size, the relationship between the residual for each observation and the sales variable can easily be subjected to test. The results of Durbin-Watson test statistics for the product, process and total patenting activity may give us some indication of selection bias due to the exclusion of firms with no patenting activity. The results of these tests are reported along with other results in the following sections of the chapter.

Another worthwhile procedure is that suggested by Scherer (1965b). He compares the estimated regression coefficients for patenting activity when the zero value firms are excluded from logarithmic regression analysis and when the firms having zero values are assigned a low patenting value of one. This procedure is followed here to give further indication of the direction of any bias. Results are reported in the following sections of the study. It should be noted that Scherer, in the same study, also recommended nonlinear regression, using squared and cubic values of the sales variable to overcome the logarithmic restriction on zero values.[1] These forms were tested on the data in this study as an alternative to the multiplicative model, with results reported in the following sections. We now turn to the regression results for firm product patenting.

1. Scherer's models are nonlinear only in the independent variables and not in the parameters.

8.3 Regression Results for Product Patenting

The OLS regression results for product patenting are discussed first, as they are somewhat richer than those for process patenting. Equations [8.1] and [8.2] below provide regression estimates for product patenting activity[1]. Equation [8.1] results when only 145 firms having positive product patenting activity are included in the regression. Equation [8.2] results when all 180 firms are used, with those firms having zero values for product patents being assigned a value of one. The second equation is listed as an aid in evaluating 'selection bias' in the estimates, discussed in the last section.

		Constant	$LogSales_{71}$	LogQSE	Stxclass	Loggrowth	Log Conc
[8.1]	Log Product Patent =	-7.44	.800	.791	.550	.221	-.347
			(7.52)***	(6.02)***	(2.85)***	(1.36)*	(1.74)**
	n=145, adj r^2=.385						
[8.2]	Log Product Patent						
	n=180, adj r^2=.411	-8.36	.858	.830	.648	.263	-.382
			***	***	***	*	**
			(8.52)	(6.62)	(3.58)	(1.60)	(2.03)

note: *** denotes significance at the one percent level, ** at the five percent level and * at the ten percent level.

In both equations listed only those patents which could be identified as product patents were included in the dependent variable. /

1. The majority of estimates listed in this chapter were obtained through the use of the SPSS computer programme, (see Nie, 1975).

variable. Regressions were undertaken where 'unidentified' patents were attributed to the product patent category in the same proportion as identified patents. Due to the small percentage of unidentified patents, results were very similar to those presented above. These results are presented in appendix 8.3.

It should be noted that the equivalents of equations [8.1] and [8.2] were also re-estimated excluding those firms which were subsidiaries of foreign parents (for example, Ford UK). Such firms, it might be argued, would have patenting policies with respect to the UK which would be different from domestic firms. In fact, excluding foreign firms makes little difference to the results and therefore these firms are retained in the estimating equations. Estimates excluding foreign subsidiaries are also presented in appendix 8.3.

Comparing the two equations, [8.1] and [8.2], it can be seen that the estimates are very similar. The coefficients in the second equation are slightly higher and attain a higher level of significance. The equation which includes the firms with zero product patenting activity [8.2] also achieves a slightly higher explanatory level or adjusted r^2

<u>Sales</u> Both equations show the logsales coefficient to be significantly different from zero at the .01 percent level. The exclusion of zero value firms in the product patenting model [8.1] does however, result in a slightly lower coefficient with respect to firm size. This suggestion of downward bias was predicted by Scherer (1965 b) for total patenting activity. When one-sided confidence

intervals /

intervals are calculated for the logsales coefficients at the .05 percent level, it is found that the coefficient representing all firms in [8.2] or .858, is not significantly different from one, the upper limit being 1.02. The logsales coefficient in [8.1] or .800 has an upper limit of .99[1].

In some respects the log sales coefficient is acting in the regression both as an indicator of the influence of demand or the size of the market on product patenting and as an indicator of supply conditions concerning knowledge production. The profit maximising model with respect to knowledge production, developed in chapter six, suggests a proportional relationship between sales and patenting activity. Assuming the objective of the firm is correctly specified, a coefficient significantly less than one would indicate diseconomies in production of knowledge arising from the increase in firm size. It should be stressed again that the results say nothing about economies of scale in the R & D unit within the firm itself. Of course the model may be misspecified for a number of firms. For example, a firm might take a strictly defensive attitude toward invention rather than following a profit maximisation hypothesis. In this case demand would not have the same strong /

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1. One-sided confidence intervals for logsales give upper limits calculated as follows:

   [8.1] $.800 + t_{.05}(\text{std error}\ \beta)$

   $.800 + (1.65)\ (.117) = .99$

   [8.2] $.858 + (1.65)\ (.101) = 1.02$

strong influence.

Taking the two results together, [8.1] and [8.2] and considering some potential for downward bias in the logsales parameter, there is scarce evidence for diseconomies of scale in product patenting among the largest UK firms. Of course, on the other hand, there is no evidence at all for any positive economies of scale.

It should be noted that while in comparing equations [8.1] and [8.2], some downward bias in the OLS logsale estimate is suggested, there is no simple or standard procedure to identify the amount of bias associated with an estimated coefficient.[1] The arbitrariness of the assignment of the value of 1 patent in equation [8.2] to firms having no product patents, can be seen when values even closer to zero are assigned. If, for example, an even smaller value of .5 product patents or .1 product patents is assigned to the zero value firms, the coefficient for logsales increases further.[2] These results point to the difficulty of handling firms with zero values when the form of the estimating equation is multiplicative. Although one and zero are close in value, the logarithmic values of the two numbers differ by negative infinity. Because it is a difficult and important issue, the possibility of /

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1. It is possible that an unbiased estimator could be calculated through the Tobit iterative solution of maximum liklihood equations. Also Fair (1977) has proposed an alternative procedure which he regards as somewhat simpler. However due to the time-consuming nature of either approach, with no guarantee of solution, neither of these procedures were undertaken.

2. The logsales coefficient increases to .936 when .5 patents is the arbitrary value assigned and to 1.06 when .1 patents is the arbitrary value.

of selection bias in the logsales estimate for product patenting needs to be pursued further.

The issue of bias in the logsales estimate can be further evaluated by observing the pattern of residuals when firms with zero patent values are excluded from the regression. As explained in section 8.2, a tendency for the error term to be negatively correlated with size in terms of sales would indicate a downward bias in the estimates. A plot of standardised residuals however, shows a fairly even distribution about a mean of zero, with no pattern emerging. When a Durbin-Watson test is carried out on the regression equation in [8.1], with firms sequenced from the largest to the smallest, the result is close to 2 or 2.23. This indicates that a null hypothesis of no positive correlation between residuals can be retained and lends support to the conclusion that no serious selection bias results from excluding zero value firms.[1] The Durbin-Watson test however, is not a strong test for bias in the OLS estimate, as bias could still exist along with a randomly distributed residual for firms included in the regression test.

The analysis with respect to firms having zero values for product patenting activity may be carried a step further, by predicting their patent values, using the coefficients shown in equation [8.1], or using the coefficients for non-zero value firms. The predicted value for the firms with no product /

1. A Durbin-Watson statistic above two indicates some negative correlation of the residuals.

product patents are displayed in table 8.3, listed by firm size from largest to the smallest. The mean of the predicted dependent variable, the log of product patents, for firms in the table is 1.48. Considering that the standard error of the regression is 1.13, if the firms listed in table 8.3 registered 1 product patent (or a log product patent of zero), thirteen of the predicted values would be within one standard error of their actual values while 30 would be within two standard errors. While the predicted values of the excluded firms are not, therefore substantially off-target, the table does indicate considerable overestimation when regression equation [8.1] is used on the 'zero-value' firms. It should be noted that the errors between predicted and actual values are, if anything, smaller at the lower end of the distribution of firms shown in table 8.3 than at the upper end, suggesting no great downward bias in the estimates when zero value firms are excluded. This analysis however is too simplistic and other variables in the equation must be considered.

What is immediately striking from table 8.3 is the concentration of consumer nondurable firms, especially in the food and drink category at the top of the distribution. In fact the largest twelve firms in the table are either in the consumer nondurable or building materials industries where technological opportunities are low. The positive predicted patenting activity for these firms suggests that the proxy used for technological opportunity may be overestimating the actual opportunities available in the industry /

Table 8.3

Firms with Zero Product Patents - Predicted Values[a]

Firm	Industry	Predicted Log Product Patent	Patents
Allied Breweries	CND	2.51	12.30
Bass Carrington	CND	2.42	11.25
Ready Mix Concrete	Mat	2.51	12.30
Spillers	CND	.90	2.46
Tarmac	Mat	2.27	9.68
Carrington Viyella	CND	1.13	3.10
Scottish & Newcastle	CND	1.76	5.81
Rowntree MacIntosh	CND	1.56	4.76
United Biscuits	CND	.78	2.18
J. Bibbey	CND	1.71	5.53
Heinz	CND	2.06	7.85
Nestle	CND	1.22	3.39
G. Cohen 600	Kap	2.36	10.60
Thomas Ward	Kap	2.07	7.92
Michelin	CD	2.00	7.39
C & J Clark	CND	-0.15	.86
NCR	Kap	1.88	6.55
Associated Biscuits	CND	0.36	1.43
Caterpillar	Kap	1.90	6.69
Manbre	CND	0.96	2.61
Rugby Portland Cement	Mat	1.02	2.77
Burroughs	Kap	1.62	5.05
Bond Worth	CD	0.33	1.39
Dupont	Chem	2.37	10.70
Crown House	Kap	2.00	7.39
Singer	CD	1.89	6.62
Paul's & Whites	CND	1.03	2.80
London Brick	Mat	0.79	2.20
Trebor Sharps	CND	0.61	1.84
Int Harvestor	Kap	1.50	4.48
CPC	CND	1.12	3.06
Rockware	CND	1.24	3.46
FH Lloyd	Kap	1.48	4.39
Harland & Wolff	Kap	1.63	5.10
Kraft	CND	0.83	2.29
Mean Value		1.48	5.38

Notes: Firms are listed in order of size, the largest firm first. Industry types are as follows: CND(consumer nondurables), CD (consumer durables, Kap(capital goods), Mat (building materials), Chem (chemicals).

[a]Predicted values shown were calculated using the TSP computer package (see Hall and Hall, 1980).

industry.

As one moves down the distribution of zero-valued firms in table 8.3, more capital and consumer durable goods firms appear. Such firms are not as inhibited by lack of technological opportunities and are predicted to be product changers for competitive reasons. Lack of sufficient market size becomes a more logical reason for their non-patenting activity. The pattern here is not pronounced however; there are a number of consumer non-durable firms at the lower end of the 'zero value' distribution also. The non-patenting activity of the smallest firms is not likely to be exclusively related to size.

A potential solution to the problem of zero values outlined above is the adoption of another functional form for the regression which doesn't restrict the dependent variable to positive values. With this in mind a number of alternative functional forms were tried, including the nonlinear model suggested by Scherer (1965b), which includes both squared and cubic values of the sales variable.[1] Unfortunately the nonlinear results are not an improvement especially in terms of their explanatory value. A problem with this form, also mentioned by Scherer is the high degree of multicollinearity between the sales variables, giving low levels of statistical significance to the coefficients. An advantage of the form is that it allows for/

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1. The equations referred to here are nonlinear in the independent variables. They are not inherently nonlinear in that they do lend themselves to linear regression.
Results for other functional forms are shown in appendix 8.3.

for both increasing and decreasing return to scale over the range of firms tested.

Results from the nonlinear regression show that for the 180 firms in the study, first increasing and then decreasing returns to scale are observed with respect to product patenting activity. The inflection point occurs at approximately the 27th largest firm in the study in terms of size[1]. These are in contrast to Scherer's (1965a) U.S. results where decreasing returns were observed except for a few giants. While the results are interesting, the low significance levels for the sales variables leads to caution in accepting them.

It is useful to compare the nonlinear regression results for the 180 firms as a whole with those when only firms with positive product patent values are included in the test. For the 145 firms with positive patents, continually decreasing returns to scale are observed.[2] This implies that the inclusion of zero value firms has the effect of raising the proportionality factor between product patenting and sales. As stated previously, the results must be interpreted /

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1. The nonlinear equation, shown in full in appendix 8.3, has a positive sales^2 term and a negative cubic term for sales.

2. The nonlinear equation, when only the 145 firms with positive product patenting are included, has both a negative sales^2 term and a negative cubic term. The regression equation is shown in full in appendix 8.3

interpreted cautiously.

The evidence compiled suggests that there is a small amount of downward bias in the logsales estimate in equation [8.1], when firms which do no product patenting are left out of the sample. This small amount of downward bias lends support to the conclusion that the relationship between product patenting and sales for the largest UK firms is not significantly different from a proportional one. This conclusion is not general however, in that it would not necessarily apply if a wider range of firms in terms of size had been included in the study.

While on the subject of the sales variable, it should be noted that the 1971 sales values used in equations [8.1] and [8.2] provide a four year lag of patenting activity on sales, with sales representing the demand variable. This lag is consistent, it was pointed out in chapter 7, with the information available on the length of R & D projects and the length of time it takes to process patent applications. A number of other sales years, 1972, 1973 and 1974, were entered into the equivalent of equation [8.1] to test for the appropriate lag. As sales years were entered which were progressively closer to the patent year (1975), the coefficients for logsales declined with lower significance levels. Appendix 8.3 contains results for the 1972 sales year for example.

The superior performance of the 1971 sales year over the others may have as much to do with the construction of the /

the patent base as with the correct specification of the lag. As explained in section 7.1, the lag of patenting on sales was changed by changing the sales year rather than the patent year. Therefore, while the patent numbers reflect the firms' ownership structure (in terms of subsidiaries) in 1971, the sales variable may reflect a changing ownership structure over time. The superiority of the four year lag is therefore accepted with caution.

When all of the sales years were entered into the regression equations simultaneously, a good deal of multi-colinearity became evident in high standard errors for the regression parameters.[1] The coefficients of the individual sales years also demonstrated rather wild overestimation and then underestimation in successive years. The failure of the explanatory power of the regression to increase when all sales were entered together suggested that attempts to establish a distributed lag would not prove productive.

QSE having established demand or sales as an important and significant variable with respect to inventive activity, the supply side of the knowledge production decision can now /

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1. The successive sales values for the 180 firms are highly correlated. The logsale 1971 variable and the logsale 1972 variable have a correlation coefficient of .99. Correlation coefficients between log 1971 sales and log 1973 sales and log 1971 sales and log 1974 sales are .88 and .97 respectively.

now be discussed. The proxy used for technological opportunity, the density of qualified scientists and engineers in the industry in which the firm's major product is classified, is significant in its logarithmic form in both equations [8.1] and [8.2]. It should be noted that the log QSE variable was entered into the regression equations using both a narrow (3 digit SIC) industry and much wider industry (industrial order) definition.[1] The wider industry definition gave slightly better results and it is these results which are reported in the equations shown. This wider industry definition also fits the concept of technological opportunity better in that a science base such as chemistry overlaps a number of different chemical industries.

The coefficient for the logQSE variable suggests that an increase in the density of QSEs in the firm's general industry category has a somewhat less than proportional effect on its patenting activity. Not too much importance should be placed on this effect however, since QSE density only broadly represents the concept of an exogenous science base.

The regression results for product patenting do show that both demand factors and supply or technological opportunity factors are important in determining patenting activity. This conclusion is consistent with that resulting /

1. As previously noted the QSE density data by industrial order is provided in appendix 7.3. As shown in the appendix, a few of the orders are broken down to capture those industries which are particularly high in technological opportunities, such as electronics.

resulting from the UK industry level study of Stoneman (1979), where the concern was with total patenting intensity.

It should be pointed out that the technological opportunity variable is diminished in terms of size of coefficient and significance when chemical firms are excluded from the regression equation. If equation [8.1] is repeated without including chemical firms the following regression results:

		Constant	LogSales	LogQSE	Stxclass	Loggrowth	LogConc
[8.3] Log Product Patent	=	-6.84	.745	.633	.770	.281	-.346
			(6.09)***	(2.98)***	(2.73)***	(1.39)*	(1.67)**

n = 126
adj r^2 = .346

The explanation lies in the combined high QSE levels and high product patenting activity of these firms, as shown in table 8.1b. At the same time, [8.3] shows that the stxclass variable grows in influence when the chemical firms are excluded from the sample. This relationship is further explored in the discussion related to the industry type dummy variable.

As discussed previously, the notion of technological opportunity is a difficult concept to deal with empirically. For this reason a number of slightly different proxies were tried in the estimating equations. The original concept of technological opportunity, may be better represented by using /

using only qualified scientists in the calculation of the industry density figure.[1] On the other hand, if technology is subject to 'laws of its own', the density of qualified engineers may more accurately reflect industrial opportunities.

Regression results show the density of engineers alone to have a stronger influence on product patenting activity than scientists and a stronger influence than the QSE variable as a whole. This might be expected due to the nature of patenting activity. It should be emphasised again that patent data is a better measure of 'run of the mill' advances as opposed to the far reaching kind which may be associated with a scientific breakthrough. The estimates merely show therefore that a strong engineering and technological base enhances the kinds of continuing small advances reflected in the patent data.

When entered into the regression equation however, the density of engineers alone is quite strongly correlated with the industrial type dummy or stxclass, with a correlation coefficient of .59. The industrial class dummy in fact becomes weak and loses its significance. The high correlation between the two variables stxclass and the density of engineers, is predictable since firms in the durable goods industrial class have a strong engineering base /

1. This assumes that only those qualifying with a science degree reflect a scientific discipline. In fact chemical and electronic engineers might also reflect the science base of an industry.

base. Results from these experiments concerning the technological opportunity variable are reported in appendix 8.3. The results also show that the density of scientists when entered on its own as the technological opportunity variable is less influential than the QSE variable including both scientists and engineers. Since the experiments offer no superior measure of technological opportunity, the original variable is retained.

A more positive step is taken in changing the technological opportunity variable to better reflect firms' diversified product line. A case in point is Unilever, whose major sales place it in the food industry, where technological opportunities are relatively low. However, a considerable portion of Unilever's sales are in detergents, which is a subcategory of the chemical industry and which has substantially richer opportunities. A breakdown of Unilever's patents by product show the largest category to be in detergents.[1]

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1. Unilever's industrial classification is based on a breakdown of its 1972 sales available from the Extel cards. A breakdown of both patents and sales by the firm shows the following distribution:

	Sales	Patent Total
Margarine & other fats	29.5	3.5
Other foods	31.7	28.7
Detergents	20.9	34.3
Toiletries	4.3	8.4
Chemicals, paper and packaging	6.9	22.4
Other	6.8	2.8

A much better account of a firm's technological opportunity could be attained by taking a weighted average of the richness of its opportunities in all of its product lines. A cruder and less ambitious test pursued here is to consider only the opportunities available to the firm in that industry in which it is significantly involved, in which the density of scientists and engineers is greatest. Significant involvement in an industry was arbitrarily set at fifteen percent of its sales. The regression equation [8.1] was repeated using the firm's highest 'opportunity' industry (QSE-high) in place of the QSE for the firm's major industry. Equation [8.4] below presents the results of this regression

	Constant	LogSales	Log High-QSE	Stxclass	LogGrowth	LogConc
[8.4] Log Product Patent =	-7.34	.770***	.902***	.530***	.198 *	-.392*
		(7.78)	(7.71)	(2.93)	(1.30)	(2.11)

n=145
adj r^2 = .457

Equation [8.4] shows that the substitution of the firm's highest opportunity QSE industry raises the explanatory power of the product patenting equation. In addition the new QSE variable has a higher coefficient and a higher level of significance than the QSE variable associated with equation [8.1]. At the same time the coefficient of the sales variable is slightly reduced. Overall the result points to a stronger role for the supply side variable of technological opportunity when more products other than the firm's major product are accounted for. The result should be viewed with caution however, in that the procedure used to accommodate /

accommodate diversification was a crude one based on only one of the firm's products other than its major product. It is also likely that the influence of other variables such as industrial growth would be strengthened by considering growth rates in industries outside of that of the firm's major product. The task of improving the representation of all of the industry variables by a weighting process was considered to be too great for the purposes of this study. The influence of diversification into high opportunity fields on the part of a firm however is shown to be worthy of further study.

Stxclass The stxclass dummy variable in this study represents the degree to which competition is based on price or product technology. Recalling the theoretical model in chapter 6, the variable is a proxy for the price and/or product quality elasticity of demand faced by the firm. In equations [8.1] thru [8.4] the stxclass dummy is given a value of one for those firms in the consumer durables and capital goods industries and a value of zero for firms in other industries. The dummy variables in the logarithmic equations shown have the effect of altering the intercept of the regressions. The variable is positive, as predicted and significant at the 1 percent level in all four equations presented, [8.1] thru [8.4]. This suggests that the type of industry or the type of competition in an industry has a systematic role in determining the extent to which a firm changes the technical characteristics of its products.

The insertion of a dummy variable into equations [8.1] through [8.4] which are in the logarithmic form, has /

has the effect of an added intercept term. In the case of equation [8.1], for example, the effect is to raise the log of product patenting by .55 for those firms in the capital goods and consumer durables industries. In terms of absolute patent numbers the effect is stronger at larger logarithmic values than smaller.[1]

The significance of both technological opportunity variables(QSE) and the industrial class dummy (Stxclass) in the product patenting equations point to the dichotomy in the firm's technological environment identified by Comanor (1967), Wilson (1977) and Schrieves (1978) (see section 5.2). These are: the richness of opportunity arising from the exogenous advances in science; and technological product rivalry arising from the ease with which the physical characteristics of products can be changed. While the two influences are related, with the logQSE and Stxclass variable having a correlation coefficient of .25 for the 180 firms, the relationship is not strong enough to ignore the separate influences. This is important as a number of economists have used industry dummy variables to represent technological opportunity (for example, see Scherer 1982).

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1. This is the equivalent to a scalar effect in the multiplicative form of the theoretical model.

The support for the dichotomy in the firm's technological environment must be modified however, when again the regression results are considered without the chemical firms included. Comparing equations [8.1] and [8.2] with [8.3] which excludes the chemical firms, it can be seen that the coefficient for stxclass increases when the chemical firms are removed. This is logical since these firms are both in the nondurable stxclass (dummy = 0) and are highly active in product patenting. Corresponding, as previously mentioned, the QSE coefficient is lower in [8.3] without the chemical firms, than in the other two equations. It is also important to note that the correlation coefficient for logQSE and the stxclass variable goes up to .63 when the chemical firms are excluded from the regression.

Industrial Growth. The theoretical model of product patenting activity discussed in chapters 6 and 7 suggests that the firm's inventive activity should be proportional to the overall rate of growth in its industry. Since most firms operate in more than one industry, the three digit industry in which the firm's major product lies was used in the calculation of the rate of growth of industry sales. The growth rate was calculated over the years 1968-1972.

The regression results in [8.1] and [8.2] indicate that industrial growth has a modest, far less than proportional effect, on product patenting activity. The coefficients for the industrial growth variable are significant in the equations shown at the ten percent level. The results imply that while overall growth provides a moderate stimulus to product invention, current levels of demand, represented by the sales variable have a much greater influence. This conclusion was also reached by Scherer (1982) in his study of patenting activity at the US industry level. The information in table 8.2 supports this conclusion. Industries with above average growth rates, for example building materials, are not necessarily active generators of product patents, although they can be as in chemicals.

Industry Concentration. The final variable, and one of the most problematic, to be discussed in relation to the product patenting equations is the concentration variable/

variable. From the theoretical consideration of the variable in previous chapters, it may be recalled that the structure of a market can have opposing influences on the incentive and innovative effort by a firm. On one hand market power can mean a greater degree of appropriability for the firm's inventions, while on the other hand, a lack of rivalry can render the firm complacent.

The results in equations [8.1] and [8.2] show the concentration variable to be significant and to be exerting a moderately negative influence on product patenting activity. The negative sign for the concentration variable suggests that the lack of stimulus from competitors overrides any increased appropriability of invention due to increased market power. It must be noted, however, that the patent application process itself, rather than invention, might also be affected by industrial concentration. It is plausible that firms in heavily concentrated industries feel less pressure to protect their inventions from rivals by taking out patents.

In the only other U.K. study to test the influence of concentration on inventive activity, Waterson and Lopez (1983) conclude that R&D intensity is at least not positively related with concentration. It is also useful, however, to compare the results of this study concerning the concentration variable with those from U.S. studies, where most of the work has been done. A number of U.S. economists, particularly Comanor (1967) and Shrieves (1978), have suggested that there may be a more complex relationship between inventive activity and concentration. They identified/

identified a strong positive relationship between concentration and technological factors (see section 5.4) which concealed the true relationship between concentration and inventive effort. They found that if technological factors were not accounted for, the positive, but weak, influence of concentration on research is overstated.

In this study when two technological factors are accounted for, the concentration variable has a negative influence on patenting activity. However, unlike the US studies, here among the top 180 manufacturing firms, there is no strong positive association between concentration and technological opportunity (QSE). In fact, the two variables have only a slight positive association, with a correlation coefficient of .15. The only other independent variable with which industrial concentration is moderately correlated is firm size, the two having a correlation coefficient of .37.

The discussion above suggests that more empirical work needs to be done in the U.K. on the relationship between inventive activity and concentration. The relationship might be further explored by using measures of concentration other than the proportion of output produced by the five largest domestic firms in the firm's major industry. For example, a measure adjusted to allow for foreign trade could be used since imports are an important source of competition in U.K. markets. The literature on the subject of concentration ratios (for example, see Curry and George, 1983) suggests that indices which accurately/

accurately reflect the foreign sector are not very easy to construct, given current data availability. Pursuit of this topic therefore is left for further study.

8.4. Regression Results for Process Patenting Activity

It should be stated firstly that the OLS regression results for process patenting activity are more difficult to interpret than those for product patenting. This is due to the fact many more of the 180 firms, just over half in fact, have zero values for the dependent variable or zero process patents. It should also be recalled that the average number of process patents among the 180 firms is 3.5 compared to 22.3 average product patents. The median value for firms with positive process patents is only two. Here the statement in the Hall, Griliches and Hausman (1984) paper, that patent counts tend to be imprecise for small values must be considered. The situation also presents a problem in the assignment of a small value to the 'zero value' firms, as was done in the case of product patents. One patent is not a particularly small number as far as process patenting is concerned. For this reason the arbitrary value of .5 is assigned to the zero value firms to obtain some basis of comparison.

The OLS regression results for process patenting, similar to [8.1] and [8.2] for product patenting, are shown/

shown in [8.5] and [8.6] below.[1] Equation [8.5] results when only the 89 firms with positive process patenting activity are used in the regression. Equation [8.6] results when all 180 firms are used, with those firms having zero values for process patents being assigned an arbitrary value of .5 process patents.[2]

While the estimated coefficients in [8.5] and [8.6] above are similar on the whole, there are some notable changes in individual coefficients particularly for stxclass and concentration. This is somewhat expected given the large number of firms excluded from [8.5]. As noted previously, this makes the task of interpreting the influence of the dependent variables on process patenting somewhat more difficult. The explanatory value of the estimated regression, does increase slightly as with product patenting, when all 180 firms are included in the test.

<u>Sales</u>. As with product patenting the sales variable is shown to be highly significant in both the process patenting equations [8.5] and [8.6]. Unlike product patenting, however, the logsales coefficients shown are both/

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1 Again, as with product patenting, only those patents which could be 'identified' as process patents were included in the dependent variable. Regressions which were undertaken with 'unidentified' patents attributed to the process category in the same proportion asidentified patents are shown in appendix 8.4. The inclusion of unidentified patents makes little difference to the regression results. Regression results with foreign subsidiaries excluded are also provided in the same appendix. These results are similar to [8.5].

2 When a value of one patent is assigned to the 'zero value' firms and the regression re-estimated, the logsales coefficient falls to .687. As noted, one is not a very small value.

		Constant	LogSales71	LogQSE	Stxclass	Loggrowth	LogConc
[8.5]	Log Process Patent =	-7.83	.755	.133	-.368	.180	-.323
			(7.15)***	(1.06)	(1.82)**	(.980)	(1.35)*
	$n = 89$ adj $r^2 = .361$						
[8.6]	Log Process Patent =	-8.71	.834	.174	.093	.279	.055
			(10.35)***	(1.73)**	(.623)	(.370)	(2.12)**
	$n = 180$ adj $r^2 = .401$						

both significantly less than one at the .05 level when one-sided confidence intervals are calculated.[1] This implies some diseconomies of firm size with respect to process patenting activity. This conclusion, however, must be questioned, given the fact that downward bias in the logsales coefficient due to the exclusion of 'zero value' firms cannot be precisely measured. In fact, if an arbitrary value of .1 process patent is assigned to the zero value firms and equation [8.6] is re-estimated, the logsales coefficient increases to 1.19. Again any clues to the extent of bias in the process patent estimates must be further explored.

As with product patenting, one clue to potential bias in the logsales estimate is the pattern of residuals when firms with zero patent values are excluded from the regression. A plot of standardised residuals about the mean from equation [8.5] shows no clear pattern emerging. However, the Durbin-Watson statistic for this equation is 1.48 meaning that the hypothesis of no positive correlation between logsales and the residual cannot be accepted.[2] While the D-W statistic is not a strong test for a bias, it points to the difficulty when over half of the cases are excluded from the regression.

If /

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1 One-sided confidence intervals for logsales are calculated as follows:

[8.5] $.755 + t_{.05}(\text{std error}) = .755 + (1.66)(.106) = .93$

[8.6] $.834 + (1.65)(.081) = .968$

2 The lower limit of the D-W statistic is 1.54 for n = 89 and 5 regressors at the .05 level.

If table 8.2 is re-examined, it can be seen that nineteen out of the twenty smallest firms in the study had no process patents. Of the second smallest twenty firms, sixteen had no process patents. This in itself poses a case for a downward bias in the logsales estimate. Due to the large number of firms with zero values in the case of process patenting activity, the analysis by individual firms, done for product patenting activity, proves cumbersome. Some information is gained, however, by attempting to fit the process patenting data to alternative functional forms.[1]

Results from the nonlinear regression for process patenting show increasing returns to firm size up to the 23rd largest firm in the study and then decreasing returns. This result is similar to the nonlinear result for product patenting. It should be noted that when only the 89 firms with positive patent values are included in the nonlinear regressions, decreasing returns over the entire size range of firms are obtained.[2] This is an indicating that the inclusion of zero value firms has the effect of moving the relationship between process patenting and sales closer to proportionality. Again, however, the low significance level of the sales variables in the nonlinear form prevent us from making a strong case.[3]

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1 A regression equation fitting the strictly linear form to the process patent data is presented in appendix 8.4.

2 The nonlinear regression equation, shown in full in appendix 8.4 has a positive sales^2 term, but a negative cubic term for sales. When only the 89 firms with positive process patenting are included in the regression the sales^2 term becomes negative and the cubic term drops out.

3 The explanatory power of the nonlinear equation (.353) is almost as great as that in [8.5] making it a viable alternative in this respect.

Given the information compiled, it cannot be stated that equation [8.5] which indicates decreasing returns to firm size, with respect to process patenting activity, is unbiased. There is some information to indicate that the logsales estimate may be biased in a downward direction. On the other hand, the case for a proportional relationship between process patenting and sales is not particularly strong and there is no indication of increasing returns to firm size. While these conclusions are unsatisfying, they are not unexpected, given the large number of firms which do no process patenting at all and the difficulty of using these cases in a multiplicative functional form.

While on the subject of the sales variable, it should be noted that the 1971 sales value fits the regression equation as well as, or better than, the other sales years tried[1]. Given that there is some theoretical support for the four year lag implied by the 1971 sales year, it is retained. It should, however, be recalled that the performance of the sales variable in this year depends to some extent on the manner in which the patent data was compiled.

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[1] Regression results using the 1972 sales year are presented in appendix 8.4.

QSE. A noticeable distinction between the process patenting results, [8.5], and the product patenting results, [8.1], is the diminished importance for technological opportunity (logQSE) in process patenting. The size of the logQSE coefficient is much lower for process patenting and of reduced significance.[1] This is not so surprising considering the discussion of the variable in chapters four and five (sections 4.2 and 5.2 respectively). Most economists have related this supply-side variable to the opportunities available for changing the characteristics of products. Given the proxy used in this study for technological opportunity, the density of scientists and engineers in the firm's general industrial class (SIC orders), there are reasons for it to be more related to opportunities for changing products than processes. If a product is sold on the basis of its technological characteristics, scientists and engineers may not only have to be employed in the R&D and production units of the firm but also in marketing and sales. This is not true of the standardised product, where there may be technological opportunities for cost reduction.

As an additional test of the influence of technological opportunity on process patenting, an alternative proxy was used in place of the QSE measure. This was the output per operative employee in the firm's major three digit industry. As explained in section 7.2, the prediction is that this variable will be negatively related to process/

1. The size of the coefficient is not altered very much when only scientists or only engineers are used in the density calculation (see appendix 8.4)

process patenting. This is because in highly capital intensive industries with high productivity levels, one would expect the opportunities for process improvement to be near exhaustion, unless completely new technologies are introduced.

The regression results for process patenting with output per operative (Qperop) as the technological opportunity proxy are reported below[1]:

The results show the output per operative variable to be negatively related to firm process patenting activity as predicted. The variable, however, may be less representative of technological opportunities available for process invention, than the costs associated with applying these inventions in actual production. As Bessant, Braun and Mosely (1980) point out in their article on the impact of microelectronics on different industries, high capital intensity combined with long life plants can be a factor retarding the introduction of microelectronics. It should be noted that Waterson and Lopez (1983), in their U.K. industry study find capital intensity to be positively related to research intensity.

Stxclass. The dummy variable, stxclass, is used in [8.5] to represent the nature of market competition faced by the firm. The variable was given a value of one for firms in industries competing on the basis of price/

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1 It should be noted that the output per operative variable was also tried as an alternative in the product patenting equation, with unsuccessful results.

		Constant	LogSales71	LogOperop	Stxclass	LogGrowth	LogConc
[8.7]	Log Process Patent =	-2.61	.741	-.539	-.159	.300	-.125
	n = 89		(7.13)***	(1.49)*	(1.52)*	(1.71)**	(.509)
	adj r^2 = .369						

price - material inputs, nondurable consumer goods and chemicals. For other firms the variable was given a value of zero. Strictly adhering to the theory developed, the coefficient for stxclass in [8.5] has the wrong sign. It was expected that firms in the more price conscious industries would be more inclined to invent new and improved processes. This hypothesis, however, may be too simplistic. If a firm changes its product characteristics, this may require it to adopt new processes as well. The negative and significant coefficient for stxclass, which is moderately influential implies that this is the case. It should be noted that the stxclass coefficient loses its significance and substantial influence when all firms are included in the regression equation in [8.6]. As noted previously, the exclusion of over half of the firms in the study in equation [8.5] makes the interpretation of results difficult.

Industrial Growth. There is no indication from the regression equations shown that general industrial growth has a strong influence on process patenting activity. Here, as with product patenting, it can be said that current levels of demand, as represented by sales, have a much stronger influence. However, like the stxclass variable, the coefficient for industrial growth changes when firms with zero process patents are included in the regression in [8.6]. The coefficient becomes somewhat higher but with a lower level of significance. Again, the difficulty in interpreting the process patenting results is highlighted.

Industry/

<u>Industry Concentration.</u> The regression results in equation [8.5] show industrial concentration to have the same moderately negative influence on process patenting activity as product patenting. Again, the lack of stimulus from competitors seems to override increased appropriability in influencing the firm's inventive decision making. As with product patenting, the result must be qualified considering the complex relationship between invention and the propensity to patent and industrial concentration. An additional doubt concerning the significance of industrial concentration on process patenting is raised when the variable loses influence in [8.6] when zero value firms are included in the tests.

8.5 Regression Results for Total Patenting

The procedure followed here will be, as in the two previous sections, to first report the regression results, in this case for total patenting activity. However, because total patenting activity is composed of product and process patenting activity, a good deal of the analysis of the regression equations is the same as that in sections 8.3 and 8.4. Rather than repeat the analysis, the procedure will be to discuss the similarities and differences between the total patenting results and those of product and process patenting. Because product patenting dominates the total patenting activity of the firms in the study, the OLS regression results for total patenting activity are similar to those for product patenting.

Equation [8.8] below provides estimates of the regression of total patenting when only those 152 firms with positive patenting activity are included in the tests.[1] Equation [8.9] results when all 180 firms are used, with those firms having zero patents again being assigned a value of one, as in the case of product patenting.

		Constant	Logsales	LogQSE	Stxclass	Loggrowth	LogConc
[8.8] Log Total Patent	=	-7.96	.872	.744	.536	.337	-.217
			(8.67)***	(6.22)***	(2.91)***	(1.67)**	(1.64)*
n=152, adj r^2 = .436							
[8.9] Log Total Patent	=	-9.09	.944	.780	.620	.267	-.351
			(9.30)***	(6.17)***	(3.30)***	(1.61)*	(1.86)**
n=180, adj r^2 = .421							

As /

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[1] Results when foreign subsidiaries are excluded from the regression are presented in appendix 8.5.

As in the previous two sections, the regression result when only firms with positive patenting numbers are tested, is similar to that when all 180 firms are used. However unlike this comparison for product and process patenting, the explanatory value of the equation is slightly higher when firms with zero patenting activity are left out of the equation. It should be recalled here that 28 firms are left out of equation [8.8] while 35 and 91 firms had zero values for product and process patenting respectively.

Sales As with product and process patenting, the value of the logsales coefficient increases when 'zero value' firms are included in regression equation [8.9] by assigning them a value of one. This suggests that there may be some downward bias in the estimated logsales coefficient. The distribution of 28 firms with no patenting activity closely resembles that presented in table 8.3 for firms with no product patents.

When a nonlinear functional form is fitted to the total patent data for the 180 firms, the results show increasing returns to scale up to the 16th largest firm, after which returns decrease.[1] Increasing returns are thus present over a wider range of firms than in either the product or process patenting equations. This is consistent with the higher logsales coefficient in the total patenting equation. When only those firms which have positive patent values are included in the nonlinear /

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1. Nonlinear regression results for total patenting are presented in appendix 8.5.

nonlinear tests, increasing returns are observed only up to the 32nd largest firm.[1] While the nonlinear results tend to support the presence of some downward bias in the logsales coefficient in equation [8.8], due to multi-colinearity among the sales variables and therefore low significance levels, the nonlinear tests must be interpreted with caution.

The coefficient of the sales variable in equation [8.8] for total patenting is higher than its counterparts for either product or process patenting in [8.1] and [8.5] respectively. This may merely reflect the fact that fewer of the 180 firms are excluded from the regression test. While the logsales coefficient in equation [8.8] is less than one, the coefficient is not as low as those of similar studies (see section 5.3).[2] In fact, using a one-sided confidence interval at the .95 percent level, it cannot be stated that the logsales coefficient is significantly /

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1. This situation is in contrast to product and process patenting where there were decreasing returns throughout the range of firms when firms with zero patent values were excluded from the nonlinear tests.

2. While not strictly comparable, Shrieves (1978) found a logsales parameter of .604 in his US study of R & D among 411 firms. He included however only firms which performed R & D. Stoneman's parameter has a high value of .731 in his regression on UK patenting activity but this is at the industry level.

significantly less than one.[1] The results imply that at least among the largest 180 manufacturing firms in the UK, there is no strong tendency toward diseconomies of scale in patenting activity. Again, it should be emphasised that the reference is to the effect of overall firm size on inventive activity. It implies nothing about the returns to scale in the R & D facility itself.

The absence of significant diseconomies of scale in the regression results is surprising in a number of respects. As previously mentioned this result is contrary to the consensus derived from the findings of other empirical studies. Soete (1979) argues that this consensus results from studies using patent data and R & D employment data which overestimate the inventive activity of small firms. However, in this study patent data is used but no significant diseconomies emerge. Another possibility, as Soete (1979) suggests, is that the 1950's and 60's data on which the consensus has been based is obsolete. While the 1970's data used in the thesis is not claimed as current, it may reflect changes in firm size and inventive activity which have taken place since the 1960's.

<u>Other</u> /

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1. The one-sided confidence interval of logsales in [8.8] gives an upper limit as follows:

$$.837 + t_{.05}(\text{std. error})$$

$$.837 + 1.66\ (.1090) = 1.02$$

Other Variables The influence and significance levels of other independent variables in the total patenting equation generally reflect those attained for product patenting. This is due to the dominance of product patenting in total patenting activity. The importance of both demand (sales and growth variables) and supply factors, in the form of technological opportunity (QSE) are evident in the regression shown in [8.8] The industrial growth variable has somewhat greater influence and the industrial concentration variable somewhat less influence in total patenting activity as compared to product patenting activity.

Both the technological opportunity variable and the stxclass variable are important and significant in equation [8.8]. This implies a dichotomy in the firm's technological environment, that was previously discussed in relationship to product patenting (see section8.3). However, just as with product patenting, the role of the chemical firms is an important one in terms of the influence of the two variables. When the chemical firms are excluded from the test, the size of the logQSE coefficient and stxclass coefficient are reversed. This result is presented in appendix 8.5.

It should be noted that the explanatory power of the total patenting equation is slightly higher than that of either the product of process patenting regressions. This is expected, as in the case of total patents, at least no errors result from classifying product or process patents to the wrong category. However, even in the total patenting regression, [8.8],the explained variation in patenting activity remains below 50 percent.[1] In the next section, reasons for the rather poor explanatory power of the regression equations are explored.

8.6 <u>The Explanatory Power of the Regression Equations</u>

There are a number of reasons for the rather low explanatory power of the regression equations. Some are associated with the type of study undertaken. In a cross-sectional, firm-level study of this type, many contributing influences remain unaccounted for. A number of these are associated with the characteristics of the firms themselves. For example, it has often been suggested that the median age of the firm's managerial staff may have a significant influence on the firm's dedication to research and development activities. Even given equivalent R & D expenditure or inventive activity, firms may have differing patent policies, /

1. When the firm's highest QSE industry is substituted for its major QSE industry in regression [8.8], the explanatory value of the regression increases to .496. This attempt at accounting for the diversity of a firm's products was also tried on the product patenting regression and is explained in section 8.3.

policies, based on their industry and their position in that industry, legal advice or tradition.

It is also a fact that firms receive varying levels of government support for their inventive and innovative activities. As noted in table 2.4a in chapter two, government funding for private industry R & D spending is highly concentrated in a few firms in the U.K. The R & D and patenting activity resulting from this government funding may not be responsive to the market forces represented in the model of inventive activity developed in this thesis. Waterson and Lopez (1983), in their UK study of R & D activity, were able to make use of industry level data to segregate privately financed R & D, which they were able to explain much better than total industry R & D. Unfortunately there is no available data on government funding of R & D at the individual firm level. As previously noted, no data source on total R & D spending by firms is available.

Further reasons for the low explanatory power of the regressions stem from the unavoidable use of proxies to represent the original variables in the theoretical model. For example, the stxclass dummy used, broadly represented the price or product quality elasticity of demand faced by the inventive firm. As discussed previously, the technological opportunity variable was also difficult to represent in the empirical work. Of course the most significant proxy was that used to represent /

represent inventive activity itself or the number of patents accepted by the patent office from a firm. The potential errors associated with the patent measure, especially when product and process inventions are distinguished, has been stressed throughout the thesis.

The functional form used to test the relationship between patenting and the independent variables, might also be responsible for the rather poor fit of the regression equations. While the empirical model was developed directly from the theoretical model of inventive activity, it was seen that the multiplicative or log linear form was not completely suited to the patent data which involves zero values for some cases. While alternative functional forms were tested, none of these were found to be any more satisfactory than the logarithmic form.

Of course questions also exist concerning the theoretical model itself. The profit-maximising hypothesis with respect to inventive activity may not be valid. In reality many firms may engage in defensive patenting activity strictly to protect their current profit levels or market shares. On the other hand, in some industries, technological change may be essential to the firm's desire for growth. Also, the representation of the inventive decision process in the study was oversimplified, in that inventive decisions were separated from other decisions made by the firm. In reality advertising, and capital investment decisions may /

may be interlinked with inventive decisions. Therefore, while the model used was not unsuccessful in identifying important variables in the inventive decision-making process, differing theoretical assumptions might have provided models with more explanatory power.

8.7 Industry Breakdowns of Patenting Activity

Up to this point in the study, the concern has been with the product and process patenting activity of the largest manufacturing firms in the UK, taken as a whole. It is useful however, to break the firms into their respective industry groups and test the regression equation. This has advantages both for the analysis as a whole and as a useful comparison with other studies which have been undertaken both in the U.S. and the U.K.

In order to minimise the number of firms excluded due to the presence of zero values in the dependent variable, only the regression of total patenting activity was undertaken on the industry groups. Even in the case of total patenting activity, the groups of building materials and chemicals both have a low number of cases. In the industry tests, the broad industrial class variable (stxclass) drops out of the test as all firms in a group have the same value.

Table 8.7 presents regression results when the total patenting regression is re-run by industry groups. The groups are those which have been used to define the stxclass variable in previous regressions or durable and nondurables./

TABLE 8.7
SUMMARY OF REGRESSION RESULTS
INDUSTRY BREAKDOWN - TOTAL PATENTING

Equation	Dependent Variable	Constant	LogSales	LogQSE	LogGrowth	LogConc	adj r^2	n
1	Log Total Patent (Durable goods firms)	-9.35	1.01 *** (6.72)	.627 *** (2.77)	.051 (.243)	-.198 (.771)	.393	85
2	Log Total Patent (Capital goods firms)	-6.01	.776 *** (4.63)	.955 *** (3.34)	.313 * (1.59)	a	.377	57
3	Log Total Patent (Consumer durable firms)	-14.4	1.24 *** (4.96)	.720 * (1.37)	-.870 (1.00)	-.500 (.650)	.469	28
4	Log Total Patent (Nondurable goods firms)	-6.69	.779 *** (4.26)	.445 * (1.30)	0.461 (1.56)	-.515 * (1.43)	.261	46
5	Log Total Patent (Consumer nondurable firms)	-8.93	.918 *** (4.29)	.119 (.230)	.245 (.726)	-.742 * (1.43)	.318	34
6	Log Total Patent (Building products firms)	-5.21	1.55 *** (3.11)	-.845 * (1.52)	-5.52 ** (2.30)	a	.440	12
7	Log Total Patent (Chemical firms)	-9.62	1.23 *** (4.60)	b	.329 (.680)	.939 (1.17)	.506	19

Note: Only firms with positive patent values are included in the regression equations presented.

[a] Significance of the variable below tolerance for computation

[b] Values for all firms are identical

nondurables. The durables group is broken down into its capital and consumer durable components, while nondurables are divided into consumer nondurables and building products. The chemical firms are not included in nondurables here, but are tested separately.

Table 8.7 shows that in the consumer durable, chemical and building materials industries, a logsales coefficient greater than one is estimated. Due to the small number of cases tested however, and the rather large standard error for the coefficients, it cannot be stated that the coefficients significantly exceed unity in any of the industries mentioned.[1] The chemical and consumer durables industries however, don't suffer from having a large number of cases excluded from the tests due to the problem of 'zero values'. There are only two firms in this category in consumer durables and one in chemicals. In building materials four firms are in this category. The results for building materials don't follow the general pattern (for example the QSE coefficient is negative) and it must be questioned whether they /

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1. For example, if a one sided confidence interval is constructed for the coefficient of logsales in table 8.7, equation 3, the following results:

$$\beta \ 7 \quad 1.24 - t_{.05(23\ d.r)} (\text{std error } \beta)$$
$$\beta \ 7 \quad 1.24 - (1.71)\ (.183)$$
$$\beta \ 7 \quad .93$$

It can only be stated that β is significantly greater than .93

they are meaningful considering the small number of cases.

The logsales coefficient for chemical firms in table 8.7 lends mild support to the results of other studies which show increasing returns to inventive activity in this industry (see section 5.3). In particular in the only other UK test of patenting activity in chemicals, that of Smyth, Samuels and Tzoannos (1972), this was also the finding. While neither significantly increasing returns for chemicals nor significantly decreasing returns for other industries can be claimed here, the logsales coefficient is above one, and above that for industries generally.

In section 8.1, it was pointed out that consumer durable firms have on average the highest level of patenting activity of all firms in the study. In addition table 8.7 implies that within this industrial category, there are at least no diseconomies of scale as far as inventive activity is concerned. Unfortunately there are no other studies with which to compare this particular result. However, the pattern emerging in this study for consumer durables is interesting, given the previous labelling of the motor vehicles industry, which dominates the group as 'non - patent conscious' (see section 8.1).

Of the more narrowly defined industry groups, only the capital goods industry has a logsales coefficient substantially /

substantially less than one.[1] It is also noticeable that, in this industry, the technological opportunity variable (logQSE) has its most substantial influence. This is not unexpected, in that the QSE values vary quite markedly among the capital goods firms, depending on whether they are mechanically, electrically or electronically oriented. The regression result for capital goods therefore is consistent with Schmookler's statement (see chapter four, section 4.1), that technological opportunities may differ with respect to which product technologies are tapped to improve a particular production technology.

In most of the industrial regressions shown in table 8.7, sales is the most influential variable. The other independent variables often are not significantly different from zero. This is somewhat expected, in that in these regressions, the firm's industrial variables may be quite similar in value. For example, in the chemical regression the QSE variable drops out altogether as all firms are given the same industry-wide value. It should be noted that the influence of concentration is negative for most industries, except for chemicals,

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1. Even in the case of capital goods the coefficient cannot be said to be significantly different from one, due to the rather high standard error. It should be noted with respect to capital goods that 11 firms were excluded from the regression due to zero values in the dependent variable.

but it doesn't reach a high level of significance. The coefficient for the concentration variable is comparatively high and negative in consumer nondurables, where generally concentration levels are above average (see table 8.1b).

8.8 Summary of the Empirical Results

The empirical tests in the thesis point to a number of important conclusions. Due to the limitations of patent data however, particularly with respect to the classification of product and process patents, these conclusions must be regarded as tentative and viewed with caution. A number of the more important empirical findings are summarised below:

1. Both demand and supply factors are important in explaining inventive activity of the largest manufacturing firms in the U.K.

2. While overall industrial growth provides a moderate stimulus to inventive activity, current levels of demand, as represented by the sales variable have a much greater influence.

3. The relationship between product patenting and sales and total patenting and sales is not significantly different from a proportional one. The same relationship for process patenting is difficult to evaluate due to the large number of firms with no process patents.

4. /

4. The technological factors, both opportunity (QSE) and competition as measured by stxclass, have a stronger and more predictable role in the product patenting equation than in the process patenting equation.

5. The technological dichotomy, pointed to by economists in the U.S., is supported by the findings. Both technological opportunity on the supply side and technological competition on the demand side have an important influence on product patenting and total patenting activity. The support must be qualified however - the classification of the chemical firms have an important influence on the result.

6. The negative influence of the concentration ratio on inventive activity points to the need for further empirical work in this area, using U.K. data.

7. Among the largest 180 manufacturing firms, chemical and consumer durable firms are on average the largest generators of patents. Patents concerning new and improved products dominate their patenting activity. Firms in these two industrial categories, along with capital goods have on average, the highest patenting intensity or patents-to-sales ratio.

8. /

8. The high logsales coefficient for the chemical firms taken separately, lends some support to the findings of other studies, showing increasing returns to scale.

9. Technological opportunities are particularly important in the capital goods industries, which through their product inventions improve the processes of purchasing industries.

CHAPTER NINE

CONCLUSIONS

The goal of this thesis has been to develop, and then to test using UK patent data, models of firm decision-making with respect to inventive activity. A particular interest of the study has been the distinction between inventive activity with respect to improvements in the firm's products as compared to improvements in the firm's production processes. The two types of inventive decisions have been separated in both the theoretical and empirical sections of the study. In this final chapter, a critical appraisal of this approach to analysing firm inventive activity is offered. After this critique implications for further study in the area, given the findings of the thesis, are outlined.

9.1 An Evaluation of the Methodology

Having reported the results of the empirical work of the thesis in the previous chapter, it must be questioned whether the approach used to investigate the inventive activity of the largest manufacturing firms in the U.K. was a useful and fruitful one. In particular, the distinction made between process and product inventions in the study and the use of patent data to measure these distinct types of inventions must be evaluated. Questions with respect to theoretical assumptions, measurement of variables and selection of firms for the study, must also be asked.

A distinctive feature of this thesis has been the separate /

separate treatment of the firm's decision to augment its knowledge concerning its products and that concerning its production process. The distinction is important because the effects of the two types of inventions may differ with respect to economic welfare. For example, while new and improved products may enhance the quality of consumption; a proliferation of incremental product changes by a firm engaging in technological rivalry is potentially wasteful. However, the importance of product innovations in the capital goods industries and their effect on productivity in purchasing industries must also be emphasised.

The two types of inventions also may have different effects on job creation or destruction. Process inventions may save on labour and be job-destroying in stagnant markets. On the other hand new and improved products can be important net generators of jobs. In fact the role of completely new industries in long-term economic growth has recently been re-emphasised by a number of economists. Given the differences referred to, the decision-making process leading to the two types of inventions should be a subject for analysis.

The firm's decisions to produce product and process inventions were treated separately in both the theoretical and empirical sections of this thesis. The main distinctions in theoretical models of product and process inventions were: (1) the effect of the invention - cost /

cost reduction or product enhancement; and (2) the benefit to the firm of the invention - expressed in price or product quality elasticity of demand. Unfortunately both of these factors are very difficult to measure and proxy variables were resorted to. The result was empirical models of product and process patenting which were very much the same.

The theoretical models were developed to identify important variables in the inventive-decision making process. In this respect former criticisms of ad hoc empirical studies of invention and innovation with no theoretical basis, were to be avoided. However, such criticism cannot be avoided altogether, as the theoretical models evolved with their future testing in mind. More complete and realistic models of invention might have been explored, but they would also have been more difficult to test. For example, the firm's decision to undertake R & D to enable it to reduce its own costs might have been considered along with the alternative choice of purchasing improved, cost-reducing capital goods. With respect to product patenting, the influence of technological rivalry was only dealt with indirectly in our model. Again, a more sophisticated representation of rivalrous behaviour might have been introduced, but again measurement posed a problem. Therefore, while there is potential for greater distinction in the theoretical models of product and process patenting, testing such models on a relatively large /

large number of firms in different industries must be seen as difficult.

A problem, already mentioned, with respect to product and process inventions was evident from early in the study. This was the role of the capital goods industry in providing product inventions which would be used in the production processes of other industries. The empirical problem directly related to this is that most firms do little process patenting themselves. The large number of firms with zero process patents rendered the evaluation of results with respect to this type of inventive activity difficult.

In retrospect, given the results and the considerable amount of time spent in the classification of product and process patents along with the potential for error; the usefulness of the approach must be questioned. While a great advantage of patent data is its availability at the individual firm level, the classification of patents into product and process categories was somewhat ambitious considering the number of individual patent specifications involved. The inappropriateness of this method for one type of study however, does not imply that it is not useful for others, perhaps with a narrower industrial scope.

The decision to test the theoretical models of product and process patenting activity on a large number of firms across a wide range of manufacturing industries had important consequences. The decision was based on a desire to study those manufacturing firms in the U.K. generating the /

the largest numbers of inventions. Also, while such studies had previously been undertaken using U.S. data, there was no comparable work in the U.K. It was also predicted, and correctly so, that differing industrial environments would have an important influence on the firm's inventive decisions. However, while a number of important findings emerge from the study (to be discussed in the next section), the number of cases, to some extent, acted as a constraint on the richness of detail which could be gathered concerning each individual firm and its industrial characteristics.

A conclusion of the thesis is that the approach distinguishing between a firm's decision to pursue product as opposed to process inventions should not be abandoned. However, the approach might be more successfully applied within a narrower framework. Here, Schmookler's original inter-industry approach is appealing. In terms of firms in a final goods industry, both their own product and process inventions and those of the industry supplying them (e.g. capital goods industry) are important. The inventive-decision making process for firms in both industries must be seen as inter-linked.

Along the same line as above, it must be said that the disadvantage of the cross-sectional approach used in this thesis, is that it looks at variables such as technological opportunity and the competitive environment in a market at a single moment in time. There may be more to be gained in future studies from considering the /

the effect of a changing industrial environment over time on inventive activity. Again this suggests a more narrowly based study than the one pursued, but allowing for inter-industry links with respect to inventive decision-making.

The ultimate constraint on all empirical studies of inventive or innovative activity however, is the data constraint. While data limitations are typical in most empirical work in economics, the problem is exaggerated in this subject area and particularly in the U.K. While a conclusion of this thesis is that patent data are an adequate measure of total firm inventive activity if interpreted cautiously, the drawbacks of this data base are considerable. A practical draw-back is the time-consuming task of tabulating patent counts for individual firms. As already mentioned, the extra effort involved in separating a firm's product from its process patents is not recommended for future studies of this scale. The micro-character of patent data and its potential should not be ignored however. For example, it would be possible to obtain some index of the diversification of a firm's inventive activity in terms of its major products, through the use of patent specifications.

The study of inventive and innovative activity among U.K. firms would be greatly enhanced, if some measure of research and development activity,at least of the largest firms, were published regularly. The existence of an available data base in the U.S. has obviously /

obviously influenced the large number of studies done at the firm level in that country. While R & D figures might, from the firm's point of view, be seen as confidential information, from society's point of view, they would aid in assessing the dynamic performance of private industry. Economists should support efforts to have the R & D activity of firms included in their annual reports.

9.2 Findings and their Implications for Further Study

While the empirical results of the study are not useful for predictive purposes, they do point to a number of important factors which influence the inventive activity of U.K. firms. A tentative finding of the thesis is that among the largest U.K. manufacturing firms it is not size, but concentration which presents the greatest hindrance to inventive activity. While firms in the study generate patents roughly in proportion to their size, the level of industrial concentration has a moderately negative influence on inventive activity as a whole. The pattern described above is similar with respect to those inventions which just enhance a firm's products. However, the influence of the size and concentration variables is less clear with respect to process patenting due to the empirical problems mentioned. Overall the findings suggest that a competitive environment is much more of a spur to invention than any abnormal ability to appropriate its rewards. This implies that any hesitation on the part of the government to contain monopoly power for technological /

technological reasons may be misplaced. And while firm size and the level of concentration in markets are related, the study suggests that it is the size variable related to the market as a whole which is important, not size alone.

While these empirical findings must be viewed with caution, considering the limitations of the data already described; given the other scarce U.K. evidence available, the role of market power in the inventive-decision making process seems worthy of further study. An additional point made in the analysis of the concentration variable, was that the U.K. evidence was not consistent with that using U.S. data. However, while differences between the U.S. and the U.K. with respect to industrial concentration have been explored, the effect of those differences on technological change in industry has been ignored.

A number of directions should be pursued with respect to the influence of concentration on invention which were viewed as limitations in this study. These are: (1) the effect of international trade on the measure of concentration and therefore on the firm's inventive activity; (2) the dual causal relationship between concentration and technological change in industry; and (3) the dynamics of the relationship in (2) above as an industry matures.

Another important empirical finding is that the firm's inventive decision-making process is influenced by supply-side factors or technological opportunities along /

along with demand factors. This finding is consistent with those of other, similar studies. While technological opportunity is important to the type of inventions which dominate firm patenting activity-product patenting, the role of the supply-side variable in process patenting by the firm appears to be weaker.

In this study a proxy variable (QSE) considered to be broadly representative of industrial technological opportunities was used in the empirical work. While this appears to have given adequate representation, further efforts to empirically approximate this important variable should be pursued. In particular some effort should be devoted to determining whether technological opportunities in industry are, as originally suggested, related to basic scientific discoveries or whether technology tends to build on itself. While this thesis made some attempts in this direction, results were inconclusive in that they appeared directly related to the measure of invention used - the patent measure.

Another question which is raised in the thesis, but not answered, with respect to technological opportunity, is the extent of its exhaustion - if any - in an industry over time. Again a dynamic treatment of the inventive-decision making process could prove to be useful. It should also be pointed out, that while technological opportunity was considered an exogenous variable with respect to the firm in this study, the variable is not one which is completely exogenous to policy influence. In /

In an age when new discoveries in science have largely been 'professionalized' adequate funding of basic scientific research in government institutions and universities, may be essential to technological changes in industry.

The influence of technological opportunity in the individual industry regressions was particularly strong in the capital goods sector. This sector is also characterised by a higher than average number of inventions in the product enhancement category. The findings of the thesis are consistent with that view of the capital goods sector exposed by Schmookler, who emphasised the importance of differing opportunities in the product technologies of goods used in the production processes of other industries. The results with respect to capital goods reinforces the need in future studies to consider the inter-industry effects of the inventive process.

Another industry highlighted in the thesis was consumer durable goods. It was found, contrary to other evidence particularly with respect to automobiles, that large U.K. firms in this industrial category have high levels of both total patenting activity and patenting intensity. According to the theoretical models developed, a high level of product invention in this industry would be consistent with the type of competition faced - technological competition. And in fact the empirical results suggest that this variable has a role in influencing the product patenting activity of firms generally.

The /

The dummy variable used to represent technological competition in the empirical work in the thesis needs to be replaced in future studies with a more precise measure of rivalry based on product technology. The relationship of this market variable with the supply-side variable of technological opportunity also deserves further exploration. While in much of the literature a high rate of industrial inventive and innovative activity is considered as a virtue, the possibility of overinvestment in incremental product changes in rivalrous conditions also deserves attention.

Finally the thesis points to the lack of comparable empirical results with regard to other UK studies on the firm's inventive decision-making process. Considering the importance of technological change to private industry and to the economy as a whole, this is surprising, even after the data difficulties are accounted for. The discussion in this last chapter suggests that both new approaches to the analysis of the firm's inventive decision-making process and new data needs to be put forth. The subject area is one deserving of considerably more attention by U.K. economists.

Appendix 7.2a

The Patent Office Classification System

Classification Key Unit	Abridgment/Abstract Volume Covering Division(s)	Subjects covered
1	A1-3	Agriculture; Animal husbandry; Food; Tobacco; Apparel; Footwear; Jewellery.
2	A4	Furniture; Household articles.
3	A5-6	Medicine; Surgery; Pesticides; Firefighting; Entertainment.
4	B1-2	Physical and chemical apparatus and processes.
		Crushing; Coating; Separating; Spraying.
5	B3	Metal-working.
6	B4-5	Cutting; H-and-tools; Containing radio-active materials; Working non-metals; Presses.
7	B6	Stationery; Printing; Writing; Decorating.
8	B7	Transport.
9	B8	Conveying; Packing; Load-handling; Hoisting; Storing.
10	C1	Inorganic chemistry; Glass; Fetrilizers; Explosives.
11	C2	Organic chemistry.
12	C3	Macromolecular compounds.
13	C4-5	Dyes; Paints; Miscellaneous compositions; Fats; Oils; Waxes; Petroleum; Gas manufacture.
14	C6-7	Sugar; Skins; Microbiology; Beverages; Metallurgy; Electrolysis.
15	D1-2	Textiles; Sewing; Ropes; Paper.
16	E1-2	Civil engineering; Building; Fastenings; Operating doors etc.
17	F1	Prime movers; Pumps.
18	F2	Machine elements.
19	F3-4	Armaments; Projectiles; Heating; Cooling; Drying; Lighting.
20	G1	Measuring; Testing.
21	G2-3	Optics; Photography; Controlling; Timing.
22	G4-6	Calculating; Counting; Checking; Signalling; Data handling; Advertising; Education; Music; Recording; Nucleonics.
23	H1	Electric Circuit elements; Magnets.
24	H2	Electric power.
25	H3-5	Electronic circuits; Radio receivers; Telecommunications; Miscellaneous electric techniques.

Source: The Patent Office, Department of Trade, Patents A Source of Technical Information (London: HMSO, 1981), pp. 22-23.

Appendix 7.2b

Examples of Product, Process and Unidentified Patents

Firm	Specification Number (Division)	Description
ICI		
Product	1406511 (C5)	Cellular polyurethanes - foams to form shoe soles
	1382062 (C_3)	Plastic composition
	1423358 (C_4)	Azo dyes for treatment of synthetic textiles
	1375165 (C_3,B_2)	Coating compositions
Process	1390614 (B_5,F_4)	Apparatus to cool thermoplastics extrudate
	1423358 (B_6)	Apparatus for printing textiles
	1415706 (B_1)	Mixing Methods
Unidentified	1380497 (C_2)	Chemical process for purifying chorinated hydrocarbons - difficult to determine
	1423659 (C_3,C_2)	Olefine polymerisation process
	1385474 (C_3)	Chemical process to purify diarylamines
	1397729 (C_2,B_1)	Phosphate catalysts - Nitrile forming catalysts
UNILEVER		
Product	1387116 (B_8)	Pouch for frozen vegetables
	1406315 (C_5)	Detergent compositions
Process	1415907 (A_5)	Apparatus for cutting cheese
	1389494 (B_8)	Microbiological analysis - drop delivering devices
Unidentified	1400719 (B_1)	Supported nickel catalysts
	1418896 (C_2)	Sulphilation reaction
FORD UK		
Product	1389600 (F_2)	Steering Columns
	1378950 (F_2)	Disc Brakes

Firm	Specification Number (Division)	Description
Process	1376695 (B_2,E)	Electrostaticially applying powder coatings to vehicle bodies
	1395603 (B_3)	Welding carbaretter throttle levers
Unidentified	1384435 (C_3)	Thermosettable powders - intermediate material - difficult to determine whether it improves product or reduces costs
	1386224 (G_1)	Determining activity of oxygen in molten metal
GEC		
Product	1390084 (H_4)	Radio signalling devices
	1380813 (H_1)	Semiconductor devices
	1388283 (H_1)	Electrodes for vacuum switches
Process	1415303 (B_5)	Laminating multi-layer printed circuit boards
Unidentified	1376595 (G_2)	Testing printed circuit boards - difficult to classify to cost reduction or product enhancement
	1409806 (F_2)	Linkwork - description too vague to classify
JOSEPH LUCAS		
Product	1376192 (F_2)	Brake control valves
	1420749 (G_3)	Fuel injection pumping
	1409261 (H_1)	Electric switches
Process	1415517 (B_5, H_1)	Making battery lids
	1381502 (B_3)	Making electrical coils
	1379551 (B_3)	Welding by fusion
Unidentified	1377188 (B_3)	Machine tools attachments - not associated with particular product or process
	1380577 (G_1)	Testing sealing rings - difficult to classify to cost-reduction or product enhancement

Firm	Specification Number (Division)	Description
PHILLIPS		
Product	1384908 (H_1)	Cathode ray tube
	1389292 (H_1)	Semiconductor devices
	1392372 (G_5)	Tape machine
Process	1383848 (B_3,H_1)	Etched patterns -making integrated circuits
	1390152 (B_5,H_1)	Flat cable - method of manufacture
Unidentified	1400120 (C_7)	Electroless - deposition of copper- difficult to trace to particular product
	1405447 (G_1,G_3)	Growing crystals - intermediate product
PLESSY		
Product	1394431 (G_4,H_4)	Automatic telephone exchanges
	1387326 (E_2,B_8)	Record player cabinet
	1383548 (C_4,F_4)	Light emitting diodes
Process	1387587 (H_2,B_3)	Making connectors for printed circuit boards
	1398516 (B_8)	Fabricating labels for telephone apparatus
Unidentified	1386092 (G_1)	Electrical testing - difficult to classify to cost-reduction or product enhancement
BRITISH OXYGEN		
Product	1380261 (A_5)	Fluid flow controls for respiratory apparatus
	1421145 (F_4)	Protective caps for gas storage containers
	1379243 (C_7,B_3)	Welding Electrodes
Unidentified	1392302 (F_4)	Liquefaction of hydrogen - hydrogen but also liquefying plant
	1416163 (F_4)	Air separation for production of gases - same difficulty as above

Firm	Specification Number (Division)	Description
PILKINGTON		
Product	1417715 (H_4)	Vehicle windscreens
Process	1420753 (C_1)	Heaters for float glass process
JOHN BROWN		
Product	1406778 (B_5)	Plastic moulding machines
	1396382 (B_3)	Milling cutters
REDLAND		
Product	1406250 (C_1,C_3)	Road-making material
Process	1400721 (B_1,F_4)	Production of coated roadstone
FISONS		
Product	1407603 (C_1)	Granular fertilizers
Process	1395906 (B_5)	Process for prilling ammonium nitrate
Unidentified	1403720 (G_1,G_4)	Temperature alarms
	1409242 (B_8,A_4)	Unitary loads - carrying stacks of sacks too vague to classify

Appendix 7.3

Density of QSEs in Employment by Industry, 1971
(Number of QSEs per 100 total employees)

	Total QSEs	Scientists	Engineers and Technologists
Food, Drink and Tobacco	.73	.51	.22
Chemicals and Allied	5.94	3.92	2.02
Metal Manufacture	1.58	.38	1.20
Mechanical Engineering	1.82	.21	1.61
Instrument Engineering	2.68	.92	1.76
Electrical Engineering	3.40	1.09	2.32
Electrical	2.12	.39	1.73
Electronic	4.65	1.76	2.89
Shipbuilding and Marine Engineering	1.17	.08	1.09
Vehicles	.90	.13	.77
Aerospace	4.27	.77	3.49
Metal Goods Not Elsewhere Specified	.77	.15	.63
Textiles	.71	.27	.44
Leather Goods and Fur	.33	.21	.12
Clothing and Footwear	.08	.04	.04
Bricks, Pottery, Glass, Cement	1.17	.48	.69
Timber, Furniture	.15	.03	.12
Paper, Printing, Publishing	.56	.33	.23
Other Manufacturing Industry	.99	.44	.55

Sources: Department of Industry, Persons with Qualifications in Engineering, Technology and Science, Studies in Technological Manpower No. 5 (London: HMSO, 1976) pp. 43-49, table 1.

Department of Employment, British Labour Statistics Yearbook 1971 (London: HMSO, 1973), pp. 132-139, table 57.

Appendix 7.4

The Stock Exchange Classification

CAPITAL GOODS	
AIRCRAFT AND COMPONENTS	Aircraft and Components
BUILDING MATERIALS	Bricks and Roofing Tiles Builders Merchants Building Materials/Quarry Products/Asbestos Cement and Concrete Paint Timber
ELECTRICAL (EX ELECTRONICS AND RADIO)	Electrical (ex Electronics and Radic)
ENGINEERING (NON ELECTRICAL)	Boiler Makers Pounders and Stampers Industrial Plants, Engines and Compressors Mechanical Handling Pumps and Valves Steel and Chemical Plant Wires and Ropes Misc. Engineering
MACHINE TOOLS	Machine Tools
SHIPBUILDING, MISCELLANEOUS	Shipbuilding Heating and Ventilating Instruments Metallurgy Special Steels

CONSUMER GOODS (DURABLE)	
ELECTRONICS AND RADIO	Electronics and Radio
HOUSEHOLD GOODS	Radio and T.V. Rental Floor Covering Furniture and Bedding Household Appliances Kitchen and Tableware
MOTORS AND DISTRIBUTORS	Motor Components Motor Distributors Motor Vehicles
CONSUMER GOODS (NON DURABLE)	
BREWERIES WINES AND SPIRITS	Breweries Wines and Spirits
ENTERTAINMENT AND CATERING	Hotels and Caterers Leisure
FOOD MANUFACTURING	General Food Manufacturing Milling and Flour Confectionery
FOOD RETAILING	Food Retailing
NEWSPAPERS AND PUBLISHING	Newspapers Publishing and Printing
PACKAGING AND PAPER	Packaging and Paper
STORES	Departmental Stores Furnishing Stores Stores, Mail-Order Stores, Multiple
TEXTILES	Clothing Cotton and Synthetic Wool Miscellaneous Textiles
TOBACCO	Tobacco
MISCELLANEOUS	Footwear Toys and Games
OTHER GROUPS	
CHEMICALS	Drugs and Pharmacy General Chemicals
OFFICE EQUIPMENT	Office Equipment

Source: The STock Exchange Offical Year Book 1971

APPENDIX 8.1

FIRMS INCLUDED IN THE STUDY

Firm	Stock Exchange Class	Total Pat	Patprod	Patproc	Unident
BAT	CND	48	30	17	1
ICI	CH	662	503	93	66
UNILEVER	CND	143	111	25	7
IMPERIAL TOBACCO	CND	18	13	5	0
BL	CD	65	39	23	3
GEC	KAP	261	239	12	10
COURTAULDS	CND	34	16	18	0
FORD	CD	149	119	19	11
ASS BRITISH FOODS	CND	1	1	0	0
DUNLOP	CD	114	83	25	6
GKN	KAP	77	52	24	1
REED INTERNAT	CND	12	8	3	1
HAWKER SIDDELEY	KAP	30	27	1	2
GALLAHER	CND	9	5	3	1
BICC	KAP	48	27	21	0
ALLIED BREWERIES	CND	0	0	0	0
DISTILLERS	CND	8	7	1	0
RHM	CND	4	3	1	0
BASS CARRINGTON	CND	1	0	1	0
TUBE INVESTMENTS	KAP	47	36	8	3
THORN	CD	25	21	4	0
TATE AND LYLE	CND	4	2	2	0
JOSEPH LUCAS	CD	476	390	76	10
COATS PATONS	CND	8	2	6	0
CADBURY SCHWEPPES	CND	11	2	9	0
PHILIPS ELECTRONIC	CD	553	499	42	12
VAUXHALL	CD	7	7	0	0
PLESSEY	CD	149	133	11	5
BOWATER	CND	9	4	5	0
BROOKE BOND	CND	4	3	1	0
METAL BOX	KAP	24	22	2	0
CHRYSLER	CD	13	12	1	0
BRITISH OXYGEN	CH	60	52	0	8
READY MIX	MAT	0	0	0	0
ARTHUR GUINNESS	CND	3	2	1	0
WHITBREAD	CND	1	1	0	0
RANK XEROX	KAP	42	40	1	1
SPILLERS	CND	0	0	0	0
RECKITT & COLMAN	CH	3	3	0	0
BEECHAM	CH	59	58	1	0
VICKERS	KAP	25	23	0	2
JOHNSON MATTHEY	KAP	27	24	3	0
GLAXO	CH	57	56	1	0
DELTA METAL	KAP	5	3	2	0
ASS PORTLAND CEMENT	MAT	4	2	2	0

IBM UK /

Firm	Stock Exchange Class	Total Pat	Patprod	Patproc	Unident
IBM UK	CD	3	1	1	1
ENGLISH CALICO	CND	6	3	3	0
CARRERAS	CND	10	6	4	0
TARMAC	MAT	0	0	0	0
CARRINGTON VIYELLA	CND	1	0	1	0
ICL	CD	32	21	11	0
S & N	CND	0	0	0	0
MASSEY-FERGUSON	KAP	23	23	0	0
DICKINSON ROBINSON	CND	29	25	4	0
ROWNTREE MACINTOSH	CND	0	0	0	0
TURNER & NEWALL	MAT	22	18	4	0
ALBRIGHT & WILSON	CH	46	43	3	0
PILKINGTON	MAT	30	12	18	0
MARS	CND	1	1	0	0
ASS ENGINEERING	CD	25	25	0	0
STANDARD TELE	KAP	118	104	11	3
JOHN BROWN	KAP	23	22	0	1
SWAN HUNTER	KAP	2	2	0	0
UNITED BISCUITS	CND	0	0	0	0
ALCAN	KAP	18	3	15	0
SIMON ENG.	KAP	49	48	0	1
J BIBBEY	CND	0	0	0	0
CLARKE CHAPMAN	KAP	20	12	8	0
WELLCOME	CH	16	15	1	0
HEINZ	CND	1	0	1	0
FISONS	CH	61	50	7	4
BRITISH ROPES	KAP	8	4	4	0
REYROLLE PARSONS	KAP	29	27	2	0
GLYNWED	KAP	1	1	0	0
NESTLE	CND	0	0	0	0
SMITHS IND	KAP	25	25	0	0
MARLEY	MAT	7	5	2	0
G COHEN 600	KAP	0	0	0	0
BIRMID QUALCAST	KAP	2	2	0	0
HOOVER	CD	11	11	0	0
KODAK	KAP	35	31	3	1
GOODYEAR	CD	1	1	0	0
THOMAS WARD	KAP	0	0	0	0
CHORIDE ELEC	CD	19	14	5	0
GESTETNER	KAP	5	5	0	0
RUBERY OWEN	CD	6	5	1	0
MONSANTO	CH	20	16	2	2
DAVY-ASHMORE	KAP	21	21	0	0
MICHELIN	CD	0	0	0	0
DUPORT	KAP	10	8	2	0
C & J CLARK	CND	3	0	3	0
WEIR GROUP	KAP	3	3	0	0
PROCTOR & GAMBLE	CH	11	9	2	0
BPB IND	MAT	17	15	2	0
LAMSON	CND	34	34	0	0
DECCA	CD	12	7	5	0
STEETLEY	KAP	11	10	1	0

REDLAND /

Firm	Stock Exchange Class	Total Pat	Patprod	Patproc	Unident
REDLAND	MAT	5	3	2	0
LEAD INDUSTRIES	KAP	5	5	0	0
NCR	KAP	0	0	0	0
BUNZL	CND	6	5	1	0
SMITH & NEPHEW	CH	12	7	5	0
LAIRD	KAP	7	6	1	0
HEPWORTH	MAT	11	10	1	0
EVER READY	CD	10	10	0	0
STONE-PLATT	KAP	39	38	1	0
COPE ALLMAN	KAP	4	3	0	1
DE-LA RUE	CD	9	9	0	0
ASS BISCUIT	CND	0	0	0	0
FOSTER WHELLER	KAP	15	13	2	0
MCKECHNIE	KAP	1	1	0	0
AUTOMOTIVE PRODUCTS	CD	52	50	2	0
CATERPILLAR	KAP	0	0	0	0
WESTLAND AIR	KAP	12	12	0	0
FERRANTI	KAP	49	48	1	0
WILLIAM PRESS	KAP	6	6	0	0
RENOLD	KAP	4	4	0	0
DOWTY	KAP	23	23	0	0
HONEYWELL	KAP	7	7	0	0
CRODA	CH	3	3	0	0
BTR	KAP	6	4	2	0
GENERAL MOTORS	CD	7	6	1	0
CAPE ASBESTOS	MAT	3	3	0	0
USMC INT	KAP	43	43	0	0
MANBRE & GARTON	CND	1	0	1	0
STAVELY	KAP	3	2	1	0
FOSECO MINSEP	CH	43	41	2	0
CHUBB & SON	KAP	6	6	0	0
LRC INT	CH	3	3	0	0
BARROW HEPBURN	CND	1	1	0	0
AVON RUBBER	CD	5	4	1	0
BAKELITE	CH	5	3	2	0
BRITISH TITAN	CH	8	5	3	0
LAPORTE IND	CH	20	19	1	0
CARPETS INT	CD	2	1	1	0
WILMOT BREEDEN	CD	17	17	0	0
RANSOME HOFFMANN	KAP	1	1	0	0
RUGBY PORT CEM	MAT	0	0	0	0
BURROUGHS	KAP	0	0	0	0
BOND WORTH	CD	4	0	4	0
ITT	KAP	8	7	1	0
MATHER & PLATT	KAP	8	8	0	0
DUPONT	CH	0	0	0	0
WILLIAM BAIRD	CND	1	1	0	0
VANESTA INT	MAT	3	3	0	0
CROWN HOUSE	KAP	0	0	0	0

BAKER PERKINS /

Firm	Stock Exchange Class	Total Pat	Patprod	Patproc	Unident
BAKER PERKINS	KAP	21	21	0	0
PIRELLI	KAP	6	6	0	0
SINGER	CD	0	0	0	0
BBA	MAT	7	7	0	0
AVERYS	KAP	14	14	0	0
SPERRY RAND	KAP	15	15	0	0
ALFRED HERBERT	KAP	4	4	0	0
PAULS * WHITES	CND	1	0	1	0
NORCROSS	CND	7	4	3	0
OZALID	CH	5	5	0	0
LOW & BONAR	CND	1	1	0	0
AMEY GROUP	MAT	2	1	1	0
BSR	CD	1	1	0	0
GENERAL GOODS	CND	3	3	0	0
LONDON BRICK	MAT	0	0	0	0
GEORGE KENT	KAP	16	16	0	0
MORGAN CRUCIBLE	MAT	5	5	0	0
TREBOR SHARPS	CND	0	0	0	0
FIRESTONE	CD	1	1	0	0
INT HARVESTER	KAP	0	0	0	0
HEAD WRIGHTSON	KAP	3	3	0	0
MAY & BAKER	CH	8	7	1	0
DOBSON PARK	KAP	25	25	0	0
MOLINS	KAP	55	55	0	0
PEGLER-HATTERSLEY	KAP	2	2	0	0
CPC	CND	0	0	0	0
BESTOBELL	KAP	2	2	0	0
ROCKWARE	CND	0	0	0	0
NOTTINGHAM MFG	CND	1	1	0	0
FH LLOYD	KAP	0	0	0	0
HARLAND & WOLFF	KAP	0	0	0	0
KRAFT	CND	0	0	0	0
APV	KAP	8	8	0	0
BORG-WARNER	CD	2	2	0	0

Notes: CND = Consumer Nondurables, CD = Consumer Durables,
KAP = Capital Goods, MAT = Material Inputs, CH = Chemicals.

Total Pat = Total Patents, Patprod = Product Patents
Patproc = Process Patents

Appendix 8.3

Additional Regression Results for Product Patenting

Equation	Dependent Variable	Constant	Log Sales[a]	LogQSE	Stxclass	Loggrowth	Log Conc	Adj r^2	n
1.0	Log Product Patent (Unidentified Patents attributed in the same proportion as identified in equivalent of 8.1)	-7.58	.812 (7.61)***	.794 (6.04)***	.546 (2.81)***	-.219 (1.34)*	-.354 (1.77)**	.388	145
2.0	Log Product Patent (8.1 without foreign subsidies)	-6.92	.776 (6.77)***	.799 (5.63)***	.561 (2.68)***	.303 (1.80)**	-.300 (1.88)**	.401	118
3.0	Log Product Patent (8.1 only using 1972 sales)	-5.49	.764 (7.16)***	.797 (5.96)***	.574 (2.92)***	.186 (1.13)*	-.339 (1.67)**	.326	145
4.0	Log Product Patent (8.1 but using scientists only in QSE variable)	-7.63	.813 (7.72)***	.541 (4.82)***	1.34 (6.66)***	.224 (1.27)*	-.427 (2.10)**	.349	145
5.0	Log Product Patent (8.1 but using only engineers in QSE variable)	-7.67	.897 (9.01)***	.833 (7.18)***	0.09 (.422)	.359 (2.25)**	-.239 (1.32)*	.431	145

Appendix 8.3 (Contd.)

Alternative Functional Forms

Equation	Form	
6.0	Nonlinear n = 180	$\frac{\text{Product}}{\text{Patents}} = \underset{(1.67)^{**}}{-30.04} + \underset{(1.75)^{**}}{.142 \times 10^{-3}\ \text{Sales}^{b}} + \underset{(1.20)}{.259 \times 10^{-10}}\ \text{Sales}^{2} \underset{(.487)}{-.302 \times 10^{-16}}\ \text{Sales}^{3} + \underset{(2.87)^{***}}{5.93\ \text{QSE}}$
	adj r^2 = .262	$+ \underset{(2.45)^{***}}{20.7\ \text{Stxclass}} + \underset{(1.96)^{**}}{188\ \text{I Growth}} - \underset{(.487)}{23.0\ \text{Conc}}$
7.0	Nonlinear n = 145	$\frac{\text{Product}}{\text{Patents}} = -30.9 + \underset{(1.80)^{**}}{.177 \times 10^{-3}\ \text{Sales}^{b}} - \underset{(.110)}{.187 \times 10^{-10}}\ \text{Sales}^{2} \underset{(.210)}{-.149 \times 10^{-16}}\ \text{Sales}^{3} + \underset{(2.70)^{***}}{6.56\ \text{QSE}}$
	adj r^2 = .244	$+ \underset{(2.16)^{**}}{22.89\ \text{Stxclass}} + \underset{(1.72)^{**}}{192.22\ \text{I Growth}} - \underset{(1.37)^{*}}{32.92\ \text{Conc}}$
8.0	Linear n = 180	$\frac{\text{Product}}{\text{Patents}} = -27.0 + \underset{(7.09)^{***}}{.118 \times 10^{-3}\ \text{Sales}^{b}} + \underset{(2.78)^{***}}{5.72\ \text{QSE}} + \underset{(2.50)^{***}}{21.0\ \text{Stxclass}} + \underset{(1.96)^{**}}{188\ \text{I Growth}}$
	adj r^2 = .24[illegible]	$\underset{(1.11)}{-21.0\ \text{Conc}}$

Note
*** indicates significance of the 1 per cent level
** indicates significance at the 5 per cent level
* indicates significance at the 10 per cent level
a 1971 sales unless specified
b sales are measured in thousands of pounds

Appendix 8.4

Additional Regression Results for Process Patenting

Equation	Dependent Variable	Constant	LogSales[a]	LogQSE	Stxclass	Loggrowth	Log Conc	adj r^2	n
1.0	Log Process Patent	-7.94	.765	.134	-.374	.187	-.325	.366	89
	(Unidentified Patents attributed in the same proportion as identified in equivalent of 8.1)		(7.22)***	(1.06)	(1.85)**	(1.02)	(1.36)*		
2.0	Log Process Patent	-7.37	.741	.097	-.391	.268	-.248	.376	74
	(8.1 without foreign subsidiaries)		(6.72)***	(.724)	(1.80)**	(1.45)*	(.976)		
3.0	Log Process Patent	-2.75	.743 (7.13)***	.147 (1.20)	-.404 (2.00)**	.179 (.810)	-.329 (1.38)*	.359	145
	(8.1 only using 1972 sales)								
4.00	Log Process Patent	-6.86	.681	.108	-0.287	0.195	0.044	.391	145
	(8.1 but using only scientists in QSE variable)		(10.34)***	(1.54)*	(2.27)**	(1.76)**	(.348)		
5.0	8.1 Log Process Patent	-6.84	.696	.168	0.045	.233	b	.401	145
	(8.1 but using only engineers in QSE		(11.06)***	(2.07)**	(.316)	(2.13)**			

Appendix 8.4 contd

Alternative Functional Forms

Equation	Form	
6.0	Nonlinear n=180 adj r^2 = .353	$\text{Process Patents} = \underset{(1.63)}{-3.33} + \underset{(2.16)^{**}}{.027\times10^{-3}\ \text{Sales}^c} + \underset{(.148)}{.325\times10^{-11}\ \text{Sales}^2} - \underset{(.351)}{.328\times10^{-17}\ \text{Sales}^3} + \underset{(2.20)^{**}}{.687\ \text{QSE}}$ $- \underset{(1.59)^{*}}{2.03\ \text{Stxclass}} + \underset{(1.53)^{*}}{22.32\ \text{Igrowth}} - \underset{(1.45)^{*}}{4.22\ \text{Conc}}$
7.0	Nonlinear n = 89 adj r^2 = .318	$\text{Process Patents} = \underset{(.063)}{.594} + \underset{(2.92)^{***}}{.0324\times10^{-4}\ \text{Sales}^c} - \underset{(.725)}{.521\times10^{-11}\ \text{Sales}^2} + \underset{(1.68)^{**}}{.911\ \text{QSE}^{*}}$ $- \underset{(1.67)^{**}}{4.2\ \text{Stxclass}} + \underset{(.503)}{13.88\ \text{Igrowth}} - \underset{(1.98)^{**}}{11.16\ \text{Conc}}$
8.0	Linear n=180 adj r^2 = .356	$\text{Process Patents} = -3.09 + \underset{(9.78)^{***}}{.025\times10^{-3}\ \text{Sales}^c} + \underset{(2.14)^{*}}{.666\ \text{QSE}} - \underset{(1.63)^{*}}{2.06\ \text{Stxclass}}$ $+ \underset{(1.54)^{*}}{22.3\ \text{Igrowth}} - \underset{(1.41)^{*}}{4.04\ \text{Conc}}$

Note:
- *** indicates significance at the 1 percent level
- ** indicates significance at the 5 percent level
- * indicates significance at the 10 percent level
- a 1971 sales unless specified
- b coefficient below tolerance limit
- c sales are measured in thousands of pounds

Appendix 8.5

Additional Regression Results for Total Patenting

Equation	Dependent Variable	Constant	Log Sales[a]	LogQSE	Stxclass	Loggrowth	Log Conc	adj r^2	n
1.0	Log Total Patent	-7.26	.837	.718	.516	.338	-.248	.436	124
	(8.1 without foreign subsidiaries)		(7.68)***	(5.52)***	(2.55)***	(2.08)**	(1.18)		
2.0	Log Total Patent	-8.14	.879	.566	.785	.291	-.360	.407	133
	(8.1 without chemical firms)		(7.74)***	(3.01)***	(3.00)***	1.76**	(1.75)**		

Appendix 8.5 contd.

Alternative Functional Form

Equation	Form		
3.0	Nonlinear n = 180 adj r^2 = .288	Total Patents =	$-33.9 + .163 \times 10^{-3}\,\text{Sales}^{b} + .590 \times 10^{-10}\,\text{Sales}^{2} - .456 \times 10^{-16}\,\text{Sales}^{3}$ (1.89)** (1.70)** (.348) (.622) $+ 7.22\,\text{QSE} + 23.00\,\text{Stxclass} + 216.29\,\text{Igrowth} - 29.5\,\text{Conc}$ (2.96)*** (2.31)** (1.90)** (1.30)*
4.0	Nonlinear n = 152 adj r^2 = .279	Total Patents =	$-33.4 + .190 \times 10^{-3}\,\text{Sales}^{b} + .246 \times 10^{-10}\,\text{Sales}^{2} - .337 \times 10^{-16}\,\text{Sales}^{3}$ (1.67)** (1.71)** (.126) (.414) $+ 7.89\,\text{QSE} + 24.39\,\text{Stxclass} + 218.77\,\text{Igrowth} - 38.9\,\text{Conc.}$ (2.84)*** (2.06)** (1.71)** (1.44)

Note:
- *** indicates significance at the 1 percent level
- ** at the 5 percent level
- * at the 10 percent level
- a 1971 sales
- b 1971 sales are measured in thousands of pounds.

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